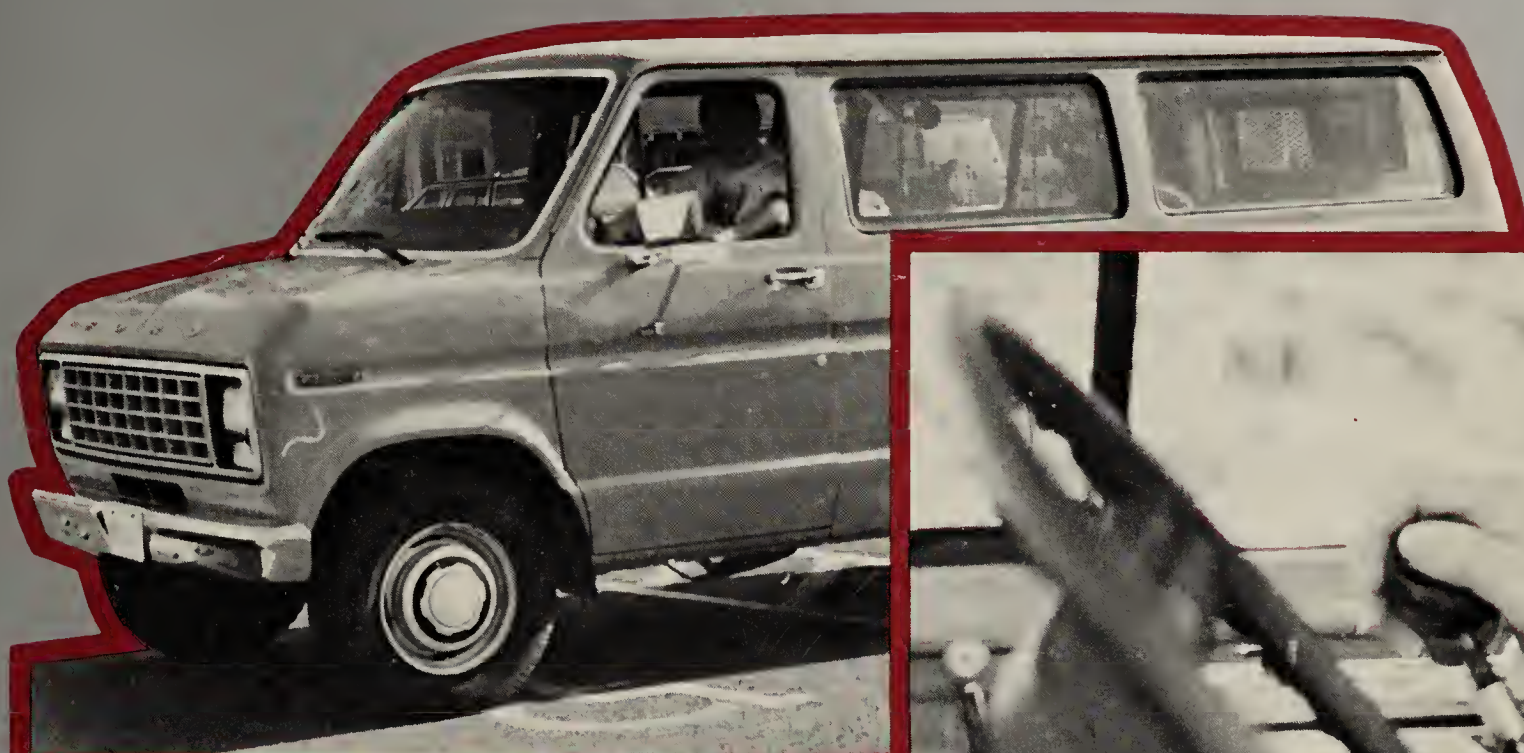




Veterans
Administration

Rehabilitation R&D Progress Reports

1987



Department of
Medicine and Surgery
Rehabilitation
Research and Development

JRRD On-Line

Selected portions of the *Journal of Rehabilitation Research and Development* (JRRD) are being put on-line as part of the VA Rehabilitation Database, and coverage will be expanded monthly. At present, abstracts of all scientific articles, Calendar of Events, and current Publications of Interest are available to readers through **JRRD On-Line**. *Rehabilitation R&D Progress Reports* for 1987 are also on-line.

Subscribers to CompuServe may access **JRRD On-Line** by typing "GO REHAB" (or "GO HUD" and selecting the "Research and Development" menu option).

JRRD On-Line is a part of the **VA Rehabilitation Database**, which is being developed to provide consumer rehabilitation research news bulletins and clinical information, as well as the *Journal*, *Progress Reports*, and other publications. A description of the **VA Rehabilitation Database** is presented on the inside back cover of this issue.

USING THE EXISTING VA REHABILITATION DATABASE ON COMPUERVE

I. What you need: Access to equipment and software.

- Personal computer
- Modem with communication software
- Subscription to CompuServe (connect time costs range from \$6/hour [300 baud] to \$12.50/hour [1200 baud], prices vary with baud rate).

II. You can get help if needed:

- VA Rehabilitation Database - write or call
Mark Malamud, Managing Editor
Office of Technology Transfer (110A1)
VA Prosthetics R&D Center
103 South Gay Street
Baltimore, Maryland 21202
Phone: 301-962-1800

III. The VA Rehabilitation Database is user friendly:

- A user friendly system is a central design feature of the database. No previous experience with computers is necessary and very little learning is required. The system makes obtaining information about rehabilitation devices as easy as making a telephone call.

IV. Eligibility:

- The VA Rehabilitation Database is available for use by anyone who subscribes to CompuServe.

V. Free/discount services:

- The Office of Technology Transfer (OTT) can assist new users in obtaining limited free CompuServe time as an introductory service.

H01786
R2266
1987
Copy # 1.
08/88



**Veterans
Administration**

Rehabilitation R&D Progress Reports

1987

AMERICAN FOUNDATION FOR THE BLIND
15 WEST 16th STREET
NEW YORK, N.Y. 10011

**Rehabilitation R&D Progress Reports
is a publication of
The Veterans Administration,
Department of Medicine and Surgery**

Rehabilitation Research and Development Service
Office of Technology Transfer (110A1)
VA Prosthetics R&D Center
103 South Gay Street
Baltimore, MD 21202

GUIDELINES FOR SUBMITTING PROGRESS REPORTS IN 1988

With the establishment of the VA Rehabilitation Database, the timing for submitting reports has expanded and will allow for reporting to be more flexible and the contents more current. The database is updated biweekly. Thus, we encourage researchers to send reports as soon as new progress is made so that their work can be updated on the database throughout the year. Additional and/or new progress reports not yet in the database will be added as they are received. (All progress reports presented in this issue are also on-line in the database.)

Reports added to the database will bear the date of receipt, so that authors and readers may readily identify new and/or updated material. (Date of receipt will not be included in the hard copy publication.)

PLEASE NOTE: In order for reports to be published in the 1988 issue of *Progress Reports*, they must be received in this office by September 1, 1988.

GUIDELINES FOR PREPARING PROGRESS REPORTS

1) Reports should not exceed 600 words. The text should contain a brief summary of the purpose, progress to date, preliminary findings and/or results over the past year, and may contain a brief statement of implications for future research, if appropriate.

Please note that reports are published solely as statements of investigators on the progress of their work and not as short research papers.

2) Reports must include the following information in addition to the text:

a) full names, titles, and addresses of the principal investigator and co-authors and the location of the research activity.

b) telephone number for the principal investigator.

c) full name and address of the sponsoring organization(s).

d) complete and accurate (i.e., exact title, author(s), publication title, volume, number, date, page numbers) references for publications resulting from the research reported; full information on patents or awards cited. (Published or accepted for publication material only)

e) a list of key words relating to each report (to be used in the *Progress Reports* subject index).

3) Submit reports in typed or printed, double-spaced format, with clearly marked page numbers. If you can, please enclose a copy of the same material on diskette (nonreturnable). We can use files saved in pure ASCII format under PC-DOS or MS-DOS, either 5 1/4" or 3 1/2" diskettes. You may also send your reports to us through CompuServe Easy-Mail. Our CompuServe ID for Easy-Mail is 76703, 4267.

We welcome contributions to the annual publication of *Rehabilitation R&D Progress Reports*. It is our desire to provide a comprehensive review of research in progress and we want to ensure that significant work is included.

Address contributions to:

Rehabilitation R&D Progress Reports
Office of Technology Transfer (110A1)
VA Prosthetics R&D Center
103 South Gay Street
Baltimore, MD 21202

Rehabilitation R&D Progress Reports 1987

Vol. 25 No. 1 of the *Journal of Rehabilitation Research and Development*

Margaret J. Giannini, M.D.
Director
Rehabilitation Research and Development Service,
Department of Medicine and Surgery, Veterans Administration

PUBLICATION STAFF

Seldon P. Todd, Jr., *Editor*
Holly M. Jellison, *Associate Editor, Managing Editor*
Tamara T. Sowell, *Associate Editor*
Ruth A. Waters, *Assistant Managing Editor*
Stanley Daly, Jr., *Senior Editor*
Beryl M. Benjers, *Assistant Editor*
Bobbi Levien, *Assistant Editor*
Mark Malamud, *Assistant Editor*
Barbara G. Sambol, *Assistant Editor*
John O. Bowman, *Chief, Technical Support*
John C. Wolke, III, *Administrative Officer*
Helen Nowotarski, *Technical Information Specialist*
Linda Majewski-Kazlo, *Chief, Data Entry Team*
M. Patricia Bush, *Data Entry Team, Circulation*

The opinions expressed in contributed material are those of the authors and those responsible for supplying the material, and are not necessarily those of the Veterans Administration.

Contents of *Rehabilitation R&D Progress Reports* are within the public domain, with the exception of material which was already under copyright when received and appears here with the permission of the copyright owner. Such copyrighted material is clearly identified as such on the page where it appears, and all such material in an issue is listed at or near this position in that issue.

Copyrighted material in this issue: NONE.

DISTRIBUTION/CIRCULATION POLICY

Rehabilitation R&D Progress Reports is distributed as number one each year of the *Journal of Rehabilitation Research and Development*. The mailing list is intended to cover all professionals in the rehabilitation field who are either actively involved in research, contemplate such involvement or need to remain familiar with the direction and methods of current research and the clinical application of its results.

At present, the *Journal* and the progress report annual publication are distributed free of charge, both in the United States and in foreign countries. Additions will be made to the mailing list upon request.

Editor's Note

Rehabilitation R&D Progress Reports 1987 is the fifth annual compilation of ongoing work in the field of rehabilitation research and engineering both in this country and abroad. Our goal of increasingly comprehensive coverage in each annual edition has been achieved once again. Moreover, authors have expanded their reporting of publications and patents resulting from completed research.

Several other changes and new features are included in this year's edition: the organization of progress reports under subject headings has been improved and a new subject index is included.

A true picture of progress in rehabilitation requires a broader perspective than that provided by a description of individual projects alone. This year, as a start toward reporting a broader perspective, sponsoring agencies were asked to provide information on their overall rehabilitation R&D strategies and priorities. Selected results are presented as a part of the Sponsor Index.

The availability of funds is clearly a part of the broader perspective which relates to current and future rehabilitation R&D progress. This year, as a start toward annual coverage of funding, a new section presenting a selected listing of agencies that fund rehabilitation R&D has been added. Hopefully, this information will assist researchers in locating additional support for their work.

Perhaps most significantly, *Rehabilitation R&D Progress Reports* are now online (see inside front cover) on the VA Rehabilitation Database and will be maintained on an ongoing basis. Thus, a researcher can report progress (including "breakthroughs") and within days have his or her report available to other scientists and over 300,000 system users. Ongoing reports will allow users to get a more current picture of activity and progress in rehabilitation R&D than an annual publication alone can provide. An annual hard copy report will continue to be published in January of each year and will be derived from the progress reports contained in the VA Rehabilitation Database.

The deadline for submission for inclusion in the next annual edition is September 1, 1988. Guidelines for submitting progress reports are listed on page ii.

Seldon P. Todd, Jr.

Electronic Publishing: A Technical Note

The organization and preparation of this publication was done on a database specifically designed for the production of the progress reports and the indexes. The programs used were dBase III+ (Ver 1.1) and the Norton Editor (Ver 1.3B). The operating system was IBM PC DOS (Ver 3.2) and hardware consisted of IBM PCs, XTs, ATs, and Compaq 386s. The database structure was designed by John Bowman, Chief, Technical Support. Another specially designed program, using Microsoft Quickbasic (Ver 3.0), needed in the final preparation phase of the text files was written by John J. Martin, VA Medical Center, Washington, D.C.

Rehabilitation R&D Progress Reports 1987

Contents

- 1 Section I. *PROJECT PROGRESS REPORTS***
- Progress reports are presented in appropriate subject categories. VA-sponsored reports are presented first and are followed by those of other participating organizations in alphabetical order by sponsor name. Multiple reports sponsored by the same organization are listed alphabetically by principal investigator.
(See next page for a topical listing.)
- 461 Section II. *SPONSOR PROGRAM SUMMARIES WITH INDEX TO PROGRESS REPORTS***
- Often, individual rehabilitation R&D projects represent parts of broader, overall programs of research. Program summaries are presented for selected sponsoring agencies.
- This section also contains the name and location of all sponsoring agencies and an index of the titles and page numbers of the projects sponsored by each agency.
- 482 Section III. *FUNDING ORGANIZATIONS***
- This is a selected list of rehabilitation research funding resources.
- 486 Section IV. *SUBJECT INDEX***
- The purpose of this index is to allow readers to identify and locate particular areas of interest within the entire text of the progress reports. Key words are taken from the text of each progress report and are listed with their corresponding page numbers.
- 489 Section V. *AUTHOR INDEX***
- This is an index of all progress report investigators and directors of sponsoring organizations with corresponding page numbers.

ON THE COVER

The UNISTIK hand vehicle controller, which represents the results of a VA/NASA Interagency Agreement carried out under the sponsorship of the VA Rehabilitation Research and Development Service. Based on the design of the NASA Lunar Rover controller, the UNISTIK device allows severely disabled individuals to drive conventional vehicles. Engineering safety and reliability testing have been completed and clinical testing is under way. A progress report on the UNISTIK device is on page 144. Photographs: Courtesy of the Spinal Cord Injury Service, VA Medical Center, Seattle, WA. Cover design by Holly M. Jellison.

Section I

Project Progress Reports

I. Amputations and Limb Prostheses

A. General

- 1 Measurement of Stratum Corneum Diffusional Conductance
- 1 Skin Blood Flow by Laser Doppler Velocimetry (LDV)
- 2 Comparison of Helium Flux, Xenon Washout and Laser Doppler Velocimetry in Skin Blood Flow
- 3 Oral Fluorescein in Patients
- 3 Fluorometric Prediction of Canine Small Intestinal Viability Following Venous Occlusion
- 4 Mechanism Based Treatments for Phantom Limb Pain
- 5 Oral Fluorescein in Animals
- 5 The Use of Quantitative Perfusion Fluorometry to Measure Relative Tumor and Liver Blood Flow after Transient Microembolization
- 6 Experimental Investigation of Joint Prosthesis Fixation

B. Lower Limb

1. General

- 6 Automated Fabrication of Prostheses and Orthoses: Evaluation/Demonstration of Roehampton CAD/CAM System
- 7 Automated Fabrication of Prostheses and Orthoses: Development of Prosthetic Socket Rectification Rules
- 7 Automated Fabrication of Prostheses and Orthoses: Development of Prosthetic Shape Comparison and CAD Software
- 8 The Effect on Gait Using Various Ankle-Foot Devices
- 8 Diabetic Neurotrophic Ulceration: Screening and Prevention Utilizing Aesthesiometry
- 9 Limb Viability: Vascular Reconstruction and Amputation Surgery
- 10 Identification of Optimal Amputation Level in Ischemic Limbs
- 10 Quantitative Perfusion Fluorometry as a Useful Adjunct to Determine the Healing of Lower Extremity Amputation
- 11 Determination of Causes and Mechanisms of Phantom Pain

- 12 Development of a Sensory Substitution System for the Insensate Foot
- 13 Novel Pace Counter Design for Lower Limb Temporary Prostheses
- 13 A Rehabilitation Shoe for the "At Risk Foot"
- 14 Objective Assessment of the Performance of Insert Materials in Diabetic Footwear
- 14 Design Modification to the Metatarsal Break of the SACH Prosthetic Foot
- 15 Comparison of Feedback Controllers for Functional Neuromuscular Stimulation
- 15 Management of Tarsal Disintegration in Leprosy
- 16 The Effect of Plantarflexion Bumper Stiffness in Single-Axis Prosthetic Feet
- 17 Gait Lab Analysis of Dynamic Elastic Response in Prosthetic Feet
- 18 Energy Cost Comparison of "Stored Energy" Prosthetic Feet with Solid Ankle Cushion Heel Prosthetic Feet

B. Lower Limb

2. Below-Knee

- 19 Prosthetics Research Study Report
- 20 CAD/CAM of Below-Knee Prostheses: Program Studies
- 21 Computer-Aided Analysis of Below-Knee Prostheses Alignment
- 22 Computer-Aided Analysis of Below-Knee Socket Pressure
- 24 Development of the ISNY Below-Knee Flexible Socket System
- 25 Patterns of Perfusion as Assessed by Quantitative Perfusion Fluorometry That Could Affect the Outcome of a Below-Knee Amputation
- 26 Diabetic Foot Ulcers—Quantifying the Effects of Nonsurgical Treatments
- 26 Finite Element Analysis of a Below-Knee Prosthesis
- 27 Design and Construction of a Bicycle Attachment for Conditioning of Below-Knee Amputees in the Early Postoperative Stage
- 28 Investigation of the Optimal Load Bearing Characteristics of Patellar Tendon Bearing (PTB) Prostheses
- 29 Functional Comparison of Single-Axis and Solid

Ankle Cushion Heel Prosthetic Feet in the
Dysvascular Below-Knee Amputee

B. Lower Limb

3. Above-Knee

- 30 Gait and Energy Expenditure in Above-Knee Amputees: Differences Between Socket Types
- 31 Geriatric Prosthetics: Design and Development of an Improved Above-Knee Socket
- 32 Myoelectrically Controlled Above-Knee Prosthesis
- 34 Optimization of Amputee Prosthesis Weight and Weight Distribution
- 35 Automated Fabrication of Lower Extremity Prosthetic Sockets

C. Upper Limb

1. General

- 36 Improved Upper Limb Prosthetics Development Program
- 37 Cosmetic Covers for Upper Extremity Prostheses (Male/Female)
- 38 Design of Prehension Systems for Upper Limb Amputees
- 38 The Use of CAD/CAM in the Design and Development of a Range of Prosthetic Components for the Upper Limb
- 39 Further Research into the Use of Room Temperature Vulcanizing (RTV) Silicone Rubber as a Cosmetic Glove Material for Upper Limb Prostheses
- 39 Research into a Modular Prosthetic Development for the Upper Limb
- 40 Improvement of Body-Powered Upper Limb Prostheses
- 41 Development of a Cosmetic Functional Prosthesis for Children
- 41 Research Into the Use of a Shape Memory Alloy as a Power Assistive Component for Upper Limb Prostheses

C. Upper Limb

2. Below-Elbow

- 42 Below-Elbow Prosthetic System
- 42 A Study of the Range of Motion of Human Fingers with Application to Anthropomorphic Designs
- 43 Powered Upper Extremity Prosthetics Research and Development Project: Development of Child-Size Electromechanical Hands
- 43 An Examination of Hand Amputees and Two Prosthetic Options

C. Upper Limb

3. Above-Elbow

- 44 Position-Servo Control of Upper Limb Powered Prostheses
- 45 Implementation of Extended Physiological Proprioception for Prosthesis Control
- 45 Extended-Limb Prostheses

- 46 An Electric Artificial Limb for Children Without Limbs
- 46 Quantification of the Functional Capability of Upper Extremity Amputees
- 48 Control of Metrical and Timing Precision in Human Movement
- 48 Two-Degree-of-Freedom, EPP-Based Arm Prosthesis for Above-Elbow Amputees
- 49 Quantification Functional Assessment of Control Systems for Elbow Prostheses
- 51 A Microprocessor-Controlled Prosthesis with Extended Physiological Proprioception
- 51 Powered Upper Extremity Prosthetics Research and Development Project: Development of a Child-Size Electromechanical Elbow
- 52 Developments in Myoelectric Control Muscle Site Identification for Electrode Placement in Myoelectric Prostheses

II. Orthotics

- 53 The Role of Pressure Distribution Measurement in Diabetic Foot Care
- 54 Effectiveness of Shock Absorbing Materials in Reducing Heelstrike Forces in Walking
- 55 Functional Kinesiology of Knee Bracing
- 55 Therapeutic Evaluation of the VA San Francisco Therapeutic Molded Shoe and Diabetic Risk Stratification
- 56 DataGlove Semi-Automated Hand Function Evaluation System
- 56 A Comparison of the Effectiveness of Flexible and Rigid Shoes in Relieving Pain at the Metatarsophalangeal Joints of Rheumatoid Arthritis Patients
- 57 Neofrakt versus Scotchcast in the Tone Reducing Ankle Foot Orthosis
- 57 The LSU Reciprocating Gait Orthosis
- 58 Development of Design Methodology for Anterior Cruciate Ligament-Deficient Knee Braces
- 58 Ambulatory Orthoses for the Severely Disabled: A Comparative Study
- 59 The Biomechanics of Flat-Foot Running
- 59 Assistance of Upper Limb Mobility
- 60 Development of a Powered Orthosis for Lower Limbs
- 60 Talus Control Ankle Foot Orthosis: A New Design
- 61 Mechanics of Ankle-Foot Orthoses
- 62 Functional Treatment of Perthes Disease

III. Total Joint Replacement and Other Orthopedic Implants

A. General

- 63 Absorbable Fixation Devices: Orthopaedic and Reconstructive Surgery (Pilot Study)

- 63 Determination of the Effects of Implant Interface Mechanics on Bone Remodeling
- 64 Implant Fixation by Postinsertion Pressurization of Polymethylmethacrylate
- 65 The Effect of Surgical Fit on the Biological and Mechanical Response to Porous Surfaced Implants
- 66 The Mechanical Properties of Porous-Coated Orthopaedic Alloy
- 67 Retrieval and Analysis of Orthopaedic Implants
- 69 A Model to Study the Mechanical Behavior of Osteoporotic Bone
- 70 Ferrographic and Biochemical Analysis of Wear Particles in Human Joints

B. Hip

- 71 Design Stress Analysis of Porous Ingrowth Hip Replacements
- 72 Effects of Treatments for Heterotopic Bone Formation on Biological Fixation
- 73 Human In Vivo Acetabular Pressure Movement
- 75 Initial Stability of Orderly Oriented Wire Mesh Porous-Coated Implants
- 75 Skeletal Aging and Disease in Failure of Hip Surface Replacement
- 76 Quantitative Analysis of Total Hip Arthroplasty on Cadaver Pelvis Stress and Strain

C. Knee

- 78 Design Concepts for a Porous-Ingrowth, Prosthetic Tibial Component
- 79 Ligament Insertions: Relations in the Moving Knee
- 80 Design of External Joint Assemblies (EJAs) Using CAD/CAM Techniques
- 80 All-Plastic Total Knee Replacement
- 80 Evaluation of Knee Performance After Various Orthopaedic Procedures

IV. Spinal Cord Injury

A. General

- 82 Clinical Evaluation of External Devices for Urinary Care of Incontinent Women
- 83 Electrical Stimulation for the Prevention of Pressure Sores: Blood Flow Measurements
- 84 Factors Influencing Joint Compliance and Reflex Mechanisms in Spinal Cord Injury
- 85 A Pilot Project on Skin Blood Flow Response to Loading
- 86 Activities of the Georgia Regional Spinal Cord Injury Center
- 86 On the Reduction of Energy Requirements for Crutch Ambulation by Paraplegics
- 87 Retrospective Analysis of the National Spinal Cord Injury Care System Database
- 88 New England Regional Model Spinal Cord Injury System

- 89 Effects of Nutritional Intervention During the Acute Phase of Spinal Cord Injury
- 90 Clinical Considerations Regarding the Penile Implant in Patients with Spinal Cord Dysfunction
- 91 Development of a Prospective Multi-Center Database for Head Injury Utilizing the Data Collection and Analysis Experience of the Model Regional Spinal Cord Injury Care Systems and the National Spinal Cord Injury Statistical Center
- 92 Assessment of Tendon Transfer Surgery in the Tetraplegic Upper Extremity
- 93 Psycho-Social Adjustment of Persons with Combined SCI and Closed Head Injury: A Longitudinal Investigation
- 94 Complications of Cognitive Dysfunction in Spinal Cord Injury
- 95 Evaluation of Shoulder Position as a Command Control Source
- 96 A Center for Acute Spinal Cord Injury: Epidemiology and Economic Costs of Spinal Cord Trauma
- 96 Body Composition and Nutrition in Spinal Cord Injury
- 96 Neurochemical Correlates of Autonomic Hyperreflexia in an Animal Model
- 98 The Health and Functional Status of Aging SCI Persons: A Feasibility Study Using Cases from Stoke Mandeville Hospital
- 98 A Computer Interface for the TIPE Seating Pressure Evaluator
- 99 Chemical Dependence and Spinal Cord Injury Outcome
- 101 Outcome Studies Pertinent to the National Model Spinal Cord Injury System
- 102 An Implantable Sensor for Two-Degree-of-Freedom Position Transduction

B. Medical Treatment

- 102 Early Detection of Pressure Sores by Means of Biomedical Indicators
- 104 A Feasibility Study on Detection of Impending Pressure Sores Using Ultrasound
- 104 A New Technique in the Assessment and Treatment of Autonomic Dysreflexia
- 105 A Pilot Study on Alterations in Blood Rheology in Spinal Cord Injured Patients
- 106 Sacral Nerve Stimulation for Neurogenic Bladder Management in Spinal Dog
- 107 Inhibition of the Hyperreflexic Bladder: Preclinical Trials
- 108 Effect of Intermittent Catheterization on Renal Stone Formation in Spinal Cord Injury Patients
- 108 Incidence, Characteristics, and Clinical Significance of Anemia in Patients with Spinal Cord Dysfunction
- 109 Pain Secondary to Gunshot Wound During the

Initial Rehabilitation Process in Spinal Cord Injury Patients

- 110 Didronel in the Prevention of Heterotopic Ossification Following Spinal Cord Injury: Determination of an Optimal Treatment Schedule
- 111 Natural History and Clinical Course of Urinary Tract Complications in Patients with Spinal Cord Dysfunction
- 112 Pathologic Effects of Recurrent Bacteriuria in Patients with Spinal Cord Dysfunction
- 113 Drug Effects on Bladder Smooth Muscle Contractility
- 114 Surface Sacral Stimulation for Bladder Management of Patients with Spinal Cord Injury
- 115 Neuroaugmentative Procedures for Modification of Abnormal Motor Control in Patients with Spinal Cord Injury
- 115 Effects of Spinal Cord Injury on Drug Metabolism
- 116 Collagen Dysfunction in Quadriplegia

C. Spinal Cord Regeneration

- 117 Electric Field Distribution in the Injured Spinal Cord
- 118 Recovery Following Incomplete Spinal Cord Injury: An Animal Model
- 118 Lower Extremity Spasticity Following Spinal Cord Injury
- 119 The Neurite-Promoting Activity of the Basement Membrane Protein Laminin
- 120 Central Nervous System Regeneration in Adult Mammals: A Study of Inappropriate Terminal Axonal Contacts
- 120 Immunocytochemical Analysis of Localized Extracellular Proteolysis During Neuronal Development
- 121 Regeneration of Spinal Projection Neurons in a Peripheral Nerve Environment
- 122 Rapid Neuronal and Glial Changes in the Spinal Cord Following Injury
- 123 The Effect of a GABA Agonist and a GABA Antagonist on Motor Recovery Following Subtotal Spinal Cord Lesions
- 123 Spinal Cord Synaptogenesis in Response to Deafferentation and Alterations in Nerve Growth Factor
- 124 A Study to Determine if Localized Extracellular Proteolysis is a Requirement for Successful Regeneration of Nervous Tissue
- 125 Modulation of Protein Phosphorylation in a Regenerating Central Nervous System (CNS) Tract
- 125 Dorsal Root Axonal Regeneration in Adult Glial Deficient Mammalian Spinal Cord
- 126 Action and Metabolism of TRH in the Spinal Cord (TBR-463)
- 127 International Symposium on Neural Regeneration

D. Rehabilitation

- 127 Hybrid Upper Extremity Orthoses for C5-7 SCI Patients
- 128 Treatment of Physiological Impotence
- 129 Interactive Videodisk Training for Self-Care Skills
- 130 Interactive Videodisk Training for Self-Care Skills (Project Extension)
- 131 Man-Machine Interface for Upper Limb Neural Prostheses
- 131 Artificial Sensory Transducers
- 132 Vocational Evaluation for Quadriplegics with a High School Education or Less
- 133 Development of a Reconditioning Exercise Program for Patients with Paraplegia
- 134 Longitudinal Assessment of the Utilization of Upper Extremity Assistive Devices Prescribed for the Spinal Cord Injured Quadriplegic
- 135 Longitudinal Assessment of Physical Therapy Factors in the Rehabilitation Process that Affect the Quality of Life of Persons with Spinal Cord Injury
- 136 Documenting and Utilizing Programs which Provide Community Adjustment and Independent Living Services for Persons with Spinal Cord Injury
- 137 Assessment, Development and Clinical Applications of Strategies to Coordinate Services for Spinal Cord Injured Clients after Discharge

V. Wheelchairs and Powered Vehicles

A. General

- 138 Evaluation of the Neutral Posture for Handicapped Utilizing Wheelchairs
- 139 Wheelchair Graded Exercise Test for Patients with Lower Limb Disabilities
- 140 Ergonomics of Manual Wheelchair Propulsion
- 140 A Model for Optimization of Wheelchair Lever Propulsion
- 141 Functionality and Durability of Manually-Propelled Wheelchairs
- 142 Development of a Motorized, Adjustable Standing Frame
- 142 Development of a Protective Foot and Leg Guard for Use in Wheelchair Sports
- 143 Testing of Gel-Electrolyte Batteries for Wheelchairs

B. Powered Controllers

- 144 UNISTIK Vehicle Controller: Safety, Reliability and Human Applications
- 144 Ultrasonic Head-Controlled Wheelchair and Interface
- 146 A Study of Powered Wheelchair Controllers
- 146 The Development and Clinical Assessment of a Universal Wheelchair Controller System

- 147 Assessment Protocol for Prescription of Powered Mobility Devices
- 148 A "Smart" Controller for Electric Wheelchairs

C. Seating Systems

- 148 Seat Cushions for the Paralyzed
- 149 A Comparative Evaluation of Special Seating for Severely Disabled Children
- 150 Computer-Aided Prescription of Specialized Seats for Wheelchairs
- 151 Weightbearing Characteristics of Soft Tissues for Body Support Applications
- 151 Toward Further Development of a Seating System for the Physically Handicapped
- 152 Comparison of Pressure Monitoring Systems
- 153 Wheeled Mobility and Improved Seating Systems

VI. Independent Living for the Disabled

A. General

- 154 Design of a New Toilet: Transfer and Access Pilot Study
- 154 Design of Showers and Bathing Fixtures for Disabled and Elderly Veterans
- 155 Handbike, an Arm-Powered Bicycle
- 156 The Use of Capuchin Monkeys as Aides for Quadriplegics
- 156 Supported Employment for Youth with Learning Disabilities
- 157 Promoting Rehabilitation Services and Policies: Worksite-Based Employee Assistance Programs (EAPs) as Effective Advocates
- 158 Research into Design Requirements for Access by Children with Physical Disabilities
- 158 Development of a Trailable Ablution Unit Able to be Handled and Used by a Wheelchair User
- 159 Enhanced Understanding of the Economics of Disability
- 160 Workstation Development for the Mobility Impaired
- 161 Construction of a Home Unit for Live-In Trailing of Assistive Devices
- 161 Documenting and Utilizing Programs that Provide Community Adjustment and Independent Living Services for Persons with Spinal Cord Injury
- 162 An Operational Definition of Independence
- 163 Parameters of Independent Living Programs: A Longitudinal Study
- 163 The Definition of "Peer": Consumer Perspectives and Significance in the Delivery of Counseling Services
- 164 Independent Living in Rural Areas: A Longitudinal Study
- 165 Production and Satellite Broadcast of Self-Help Videotapes for the Handicapped
- 166 Development of Design Criteria and Performance Standards for Barrier-Free Environments
- 166 Computerized Task Guidance for Cognitively Impaired People
- 167 An Infant Crib for Use by Wheelchair-Bound Parents
- 168 Multi-Adjustable Forearm Support Walker
- 168 Walker for the Young Cerebral Palsied Adult
- 168 Rehabilitation Engineering Center
- 169 Systems to Enable Physically Handicapped Persons to Board Inter-City Buses
- 170 Development of a Wheelchair-Accessible Weight Training Gym

B. Robotics

- 171 An Instructable Robotic Aid: A Pilot Proposal
- 171 Clinical Evaluation of the JHU/APL Robotic Arm
- 173 Application of a Robotic Aid for the Severely Physically Disabled
- 173 Evaluation of a Desk-Top Robotic Aid with High-Level Quadriplegics
- 174 Design of a Desk-Top Environment for a Robotic Aid for the Severely Disabled
- 175 Development of a Mobile Robotic Aid for the Severely Disabled
- 176 Robot Arm/Work Station System for High Spinal Cord Injured Persons
- 177 A Robot Feeder
- 178 Spartacus and Manus: Telethesis Developments in France and the Netherlands
- 179 A Potential Application in Early Education and a Possible Role for a Vision System in a Workstation Based Robotic Aid for Physically Disabled Persons
- 179 Manipulative Appliance Development in Canada: Neil Squire Foundation Project
- 180 An Independent Vocational Workstation for a Quadriplegic
- 181 Small Robot Arm in the Workplace to Aid in the Employment of Severely Physically Disabled Persons
- 181 CALVIN: A Robot Control Language for Rehabilitation Robotics

C. Communication Methods and Systems

- 182 A Systematic Analysis of Communicative Interaction Between a Nonspeaking Physically Disabled Child and a Speaking Peer: Pilot Study
- 183 Assessment of the Effectiveness of a Small, High Quality Speech Synthesizer in Augmenting the Communication of Non-Speaking Individuals
- 183 Matching of Computers and Interfaces to the Needs of Tetraplegic Patients
- 184 Evaluating the Effectiveness of Direct Client Intervention and Facilitator Training for Communication Intervention with Nonspeaking Physically Disabled Children
- 185 Towards Universality of Access to Information: Systems Software to Aid Access to

- Microcomputers by Physically and Multiply Disabled Students
- 186 The Development and Clinical Evaluation of a Radio Frequency Linked, Computer-Based, Voice-Controlled Workstation for the High Level Quadriplegic
- 187 Toward Development of a Protocol for Assessing the Communicative Interaction Skills of Nonspeaking Severely Handicapped Individuals
- 188 Toward Development of a Universal Modular Wheelchair Tray for Communication, Mobility and Activities of Daily Living (ADL)
- 188 PACA—Portable Anticipatory Communication Aid
- 189 Available Motions of Hand, Mouth, and Head Stick Users: Applications to Keyboard Designs
- 190 International Compatibility Standards for Electronic Communication and Interface Devices
- 191 Computer Accessibility: Support of the Industry/Government Initiative
- 192 ALTKEY: A Multi-Mode Input Program for the IBM-PC
- 193 Assessment and Prescription of Writing Aids for Physically Handicapped Children
- 193 Evaluating the Effectiveness of Direct Client Intervention and Facilitator Training in Communication Intervention with Nonspeaking Physically Disabled Children: Pilot Study
- 195 COGORTH: Cognition Orthosis Programming Language
- 196 Application of Technology to Enhance the Employability of Severely Communicatively Impaired Individuals
- 197 A Model for the Assessment of the Written Communication of Nonspeaking Physically Disabled Individuals Who Use Microcomputers
- 198 Development of a Toy Control Program for the Apple IIe

D. Private/Public Programs

- 199 Development of the Occupational Therapy Comprehensive Functional Assessment (OTCFA)
- 200 Improving Management of Vocational Rehabilitation Services
- 201 Progress Report for the PEER Regional Network
- 201 Program in Social and Independent Living Skills
- 203 Advances in Psychosocial Rehabilitation
- 203 Developing a Clear Image of the Family: The Card Sort Procedure as an Easy and Precise Method for Measuring Family Process in the Rehabilitation Setting
- 204 How Much Self-Sufficiency Does an Adolescent with a Disability Have? A New Approach to Accurate Measurement
- 205 Family-Centered Interventions for People with Chronic Physical Disabilities: The Eight-Session Multiple Family Discussion Group Program
- 206 The Acceptance of Disability Scale
- 207 The Issues in Disability Scale: A New Cognitive and Affective Measure of Attitudes Toward People with Physical Disabilities

VII. Functional Electrical Stimulation

A. General

- 209 The Use of EMG Biofeedback and Functional Electrical Stimulation in Spinal Cord Injury
- 210 Muscle Re-education in Incomplete Quadriplegia by Electrical Stimulation
- 211 Electrical Stimulation of Fast and Slow Skeletal Muscle
- 211 Intramuscular Electrical Activation of the Diaphragm
- 212 Electrical Stimulation of Paralyzed Muscle after Spinal Injury
- 213 Therapeutic Electrical Stimulation (TES) in the Rehabilitation of Children with Cerebral Palsy
- 214 Comparative Electromyography of Orderly and Reverse Recruitment Studied with FES
- 214 Development of a Stimulation System for Manipulating Muscle Force with Various Firing Rate and Recruitment Control Strategies
- 215 Value of Electrical Stimulation on Fertility in Male Patients with Spinal Cord Dysfunction
- 215 A Multichannel Biotelemetry System
- 217 Mechanism of Torque Generation: Implications for Stimulation Therapy
- 217 The Use of EMG as Force Feedback in Closed-Loop Electrical Stimulation System
- 217 EMG-Force Models in Muscles with Various Firing Rate and Recruitment Strategies
- 218 Control of Joint Motion with Synergistic Stimulation of Its Agonist/Antagonist Muscles
- 218 Closed-Loop Control of Functional Neuromuscular Stimulation Using Implantable Force Sensors
- 219 Neuromuscular Stimulator with EMG Pick-Up Circuitry
- 219 Properties and Control of Stimulated Muscles

B. Upper Limb Applications

- 220 Portable Functional Neuromuscular Systems for Upper Extremity Control
- 221 Quantitative Assessment of a Functional Neuromuscular Stimulation Motor Prosthesis for Restoration of Grasp in the Quadriplegic Hand
- 222 Feasibility Assessment of a FNS Hand Orthosis for Quadriplegics
- 223 Miniature Sensor for Two-Degree-of-Freedom Position Transduction

- 224 Sensory Augmentation for FNS Upper Extremity Prostheses
- 225 Artificial Sensory Transducer
- 226 Implantable Systems for Stimulation of Skeletal Muscle
- 226 An Externally Powered, Multichannel, Implantable Stimulator for Control of Paralyzed Muscles
- 227 Elbow Control in the C5-C6 Quadriplegic Using Functional Neuromuscular Stimulation
- 228 Analysis and Development of Coordination Programs for Hand Grasp in the Tetraplegic Using Functional Neuromuscular Stimulation

C. Lower Limb Applications

- 229 Electrical Stimulation of Osteogenesis Using Selected Techniques
- 230 Fitness Improvements and Physiological Responses to FES Exercise
- 231 Functional Tasks Restored in Paralyzed Man Using Electronic Orthotics
- 232 Functional Tasks Restored in Paralyzed Man Using Electronic Orthotics (Project Extension)
- 233 EMG as Force-Feedback in Closed-Loop Functional Electrical Stimulation
- 234 Computer Models for Designing Functional Electrical Stimulation Systems for Paraplegic Standing and Walking
- 235 Development of an Improved Walking System for Paraplegics with FES Adjunct to the LSU Reciprocating Gait Orthoses
- 236 Feedback Control of Hand Grasp During Functional Neuromuscular Stimulation
- 236 Physiological Benefits of Electrical Stimulation of Paralyzed Muscle
- 237 Hybrid Brace for Paraplegic Gait Restoration

VIII. Functional Assessment

- 238 Portable Motorized Standing Aid
- 238 Development of a Life Satisfaction Scale Applicable for People with Severe Disabilities
- 239 An Investigation into the Benefits of Upright Stance and Ambulation in the Severely Disabled
- 240 New Motor Control Assessment Techniques for Evaluating Individuals with Severe Handicaps
- 240 Comparative Evaluation of Body Support Systems for Tissue Pressure Distribution
- 241 Validation of a Gross Motor Function Measure (GMFM) for Assessment of Outcome in the Treatment of Cerebral Palsy
- 242 Pre-Clinical Research in Neuromuscular Diseases and Muscle/Nerve Biology
- 243 Clinical Research in Neuromuscular Diseases
- 244 Rehabilitation Management of Neuromuscular Diseases Research and Training Center, UC Davis
- 244 Mobile Assessment Laboratory

- 245 Computer-Assisted Driver Assessment System
- 246 Psychometric and Performance Predictors of Driving Ability
- 246 Small-Scale Vehicle for Driver Assessment/Evaluation and Training
- 247 Development of a Uniform National Data System for Medical Rehabilitation
- 248 Predictive Assessment in Prescription of Functional Aids for the Motor Disabled
- 249 Prospective Study of Factors in Back Pain Disability
- 250 Regaining Functional Abilities after Hip Fracture
- 251 Gross Motor Attainments in Eleven to Fourteen-Year-Old Children with Down's Syndrome
- 251 Orthokinetic Orthoses: Clinical Efficacy Study in Non-Drug Analgesia of Post-Trauma Chronic Pain
- 253 The Quantitative Assessment of Knee Orthoses for Control of Ligamentous Instability
- 253 A Survey of the Current Clinical Use of Gait Analysis in the UK
- 254 Anterior versus Posterior Walkers for Children with Cerebral Palsy: A Gait Analysis Study

IX. Biomechanics

A. Bone and Joint Studies

- 255 Relation of Computerized Axial Tomography (CAT) Scan Mineral Density to Mechanical Properties of Vertebrae
- 256 Prediction of Trabecular Bone Strength and Modulus by Computerized Axial Tomography (CAT)
- 256 Biomechanical Modeling of the Lower Back
- 257 Dynamic Biomechanics of Spinal Implants
- 258 Pathokinesiology of Anterior Cruciate Ligament Deficiency
- 259 Effect of Ligamentous Instability on Knee Joint Proprioception
- 259 Study of Bone Structural Response to Altered Loading
- 260 Bone In Vivo and In Vitro Stress and Strain Patterns
- 261 Biomechanical Testing of Spinal Instrumentation Systems
- 261 Evaluation of the Slide Board Exercise for Anterior Cruciate Ligament Rehabilitation
- 262 Biomechanical Testing of a New Anterior Construct for Segmental Spinal Fusion
- 263 Knee Biomechanics of Athletes with High Risk Exposure to ACL Injury
- 263 Biomechanics and Electromyography of Anterior Cruciate Ligament (ACL)-Deficient Knees
- 263 Quantification of Mobility Performance for Functional Assessment, Diagnosis, and Therapy of Neuromuscular, Skeletal, and Synovial Joint Dysfunctions
- 266 Segmental Bone and Joint Replacement after Tumor Resection

- 267 Biomechanics of Metastatic Defects in Bone
- 267 A Comprehensive, Quantitative, Predictive Model of the Human Knee Joint
- 268 Biomechanics of Joint Motion
- 269 Kinematics of the Ankle and Subtalar Joint
- 269 Ground Reaction Torque and Subtalar Joint Function
- 270 Biomechanical Evaluation of the Patellofemoral Joint Under Various Degrees of Fixed Rotational Deformities of the Femur

B. Human Locomotion and Gait Training

- 271 WATRACK—A New System for Studying Movement
- 271 Development of a Posture Sensor and Sensory Biofeedback System for Use in Gait Training of the Locomotion Disabled
- 272 Measurements of Postural Sway
- 272 A Model for Postural Sway
- 273 The Clinical Application of Gait Analysis
- 273 The Effects of Proximal Tibial Osteotomy and Tibial Tubercle Elevation on Knee and Ankle Joint Loading
- 274 Quantitative Measures for Assessing Therapeutic Effectiveness
- 275 A Telemetric Data Acquisition and Processing System for Biofeedback Training and as a Diagnostic for Human Movement Training
- 276 Feasibility Study: Evaluation of Total Knee Replacement by Gait Analysis
- 277 A Clinical Gait Recording System
- 277 Gait Abnormalities in Hemiplegia: Their Correction by Ankle-Foot Orthoses

C. Other

- 278 Optimal Biomechanical Design/Development of Arm-Powered Mobility Devices
- 279 Biofeedback System for Postoperative Hand Rehabilitation
- 279 Dynamic Positional and Electromyographic Monitoring of Sitting Posture
- 280 Mechanics of Rising from the Seated Position
- 280 A New Approach to Muscle Training to Rehabilitate the Hand in Leprosy
- 281 Comparison of Floor Sitting and Wedge Kneeler: Their Effect on Posture and Upper Extremity Range of Motion in Children with Cerebral Palsy
- 282 Design of Instrumentation to Quantify Upper Extremity Motor Control of Children with Cerebral Palsy: Pilot Study

X. Wound and Fracture Healing

- 283 Stress Analysis of Internal Fracture Fixation of Long Bones
- 284 Testing of Design Parameters for a Prototype Piezoelectric Internal Fixation Plate

- 285 Synthetic Bone Graft Materials in Segmental Defect Fractures
- 286 Noninvasive Assessment of Fracture Healing
- 287 Enhancement of Wound Healing, Using Synthetic Skin, Electrical Stimulation and Hyperbaric Oxygen Therapy
- 288 Circulatory and Mechanical Response of Skin to Compression Loading
- 289 Morphologic and Ultrasonic Analysis of Normal and Ischemic Human Wounds
- 290 Altered Collagen and Wound Metabolism in Non-Healing Diabetic Ulcers
- 291 Edinburgh Unilateral External Fracture Fixation Device
- 291 Enhancement of Ulcerated Tissue Healing by Electrical Stimulation
- 292 Acceleration of Fracture Healing by Electrical Fields
- 292 A Study on Disintegration of Carpal Bones in Leprosy
- 293 Graded Weightbearing in Tarsal Disintegration in Leprosy

XI. Muscles, Ligaments, and Tendons

A. General Properties of Muscle

- 295 Decomposition Analysis of the Surface Electromyogram
- 296 Automatic Decomposition of the Electromyogram
- 297 The Myoelectric Signal Decomposition Technique
- 297 Surface Electrode Design
- 298 Myoelectric Signal Quality Analyzer
- 298 The Frequency Response of Skeletal Muscles: Dependence on Control Strategies and Fiber Types
- 299 Skeletal Muscle Reaction to Immobilization

B. Muscle Contraction

- 299 Decomposition of Surface-Detected Myoelectric Signals
- 300 Muscle Force Output During Voluntary Contractions
- 300 Cross-Talk Between Myoelectric Signals of Adjacent Muscles
- 301 Synchronization of Motor Unit Discharges
- 302 The Common-Drive Principle of Motor Unit Control
- 302 Exercise-Induced Adaptations of Skeletal Muscle Grafts
- 303 Motor Control in Subjects with Clinical Disorders

C. Muscle Fatigue

- 303 Muscle Fatigue and Back Pain
- 304 Muscle Fatigue and Respiratory Failure
- 305 Muscle Fatigue and Myoelectric Signal
- 305 Muscle Fatigue Monitor

- 306 Motor Unit Properties Investigated by Voluntary and Electrically Elicited Contractions

D. Ligaments and Tendons

- 306 Structural and Functional Properties of Normal and Healing Ligaments
307 Structural and Functional Properties of Normal and Healing Ligaments (Project Extension)

XII. Neurological/Vascular Disorders

A. General

- 309 Electrophysiological Studies on Nerve Repair and Regeneration
310 Nerve Coupler: Sutureless Peripheral Nerve Repair at the Fascicular Level
310 Factors Limiting the Tactile Perception of Form
311 Neural Pathways Involved in Tactile Discrimination
311 A New Approach in the Relief of Pain of Leprous Neuritis
312 Treatment of Leprous Neuritis by Perineurial Steroid Injection
313 Inhibitive Casting as an Adjunct to Therapy in Children with Cerebral Palsy

B. Arthritis

- 314 Evaluation of Osteoporosis by Ultrasound and CAT-Scan
315 Arthritis Rehabilitation Unit
315 Impact of Arthritis Self-Care for Rural Persons
316 Endurance Training with Management of Fatigue in Rheumatic Arthritis and Systemic Lupus Erythematosus
317 Multipurpose Arthritis Center: Community Component—Coping Responses to Rheumatoid Arthritis
317 General Clinical Research Center: "Riadura" and NSAID in Rheumatoid Arthritis Treatment
317 Multipurpose Arthritis Center: Professional Education in Sexual Rehabilitation of Arthritis Patients
318 Multipurpose Arthritis Center: Education Component—Arthritis Patient Education Model
319 A National Arthritis Data Source (ARAMIS)
319 Multipurpose Arthritis Center: Stanford, CA
320 Northeast Ohio Arthritis Center Support: Legal Aspects of Chronic Illness: A Study of Arthritis Patients
321 Multipurpose Arthritis Center: Community Component—Arthritis Impact Measurement Scales
321 Occupational Role Dysfunction in Illness: Comparisons with Normative Data
322 Multipurpose Arthritis Center: Problem-Oriented Educational Program for Arthritis Using Aerobic-Type Exercise

- 322 Study of Behavioral Aspects of Rheumatoid Arthritis
323 UCSF Multipurpose Arthritis Center: Community Component—Studies Using a Panel of Rheumatoid Arthritis Patients
324 Benefit and Cost Comparison Between a Coordinated Team Care Approach and a Traditional Office Based Approach to Outpatient Management of Rheumatoid Arthritis

C. Low Back Pain

- 325 Myoelectric Analysis of Human Spine Function: Myoelectric Measurement of Human Muscle Endurance
326 Evaluation of Psychophysiological Ways to Assess Chronic Low Back Pain
326 Low Back Pain Studies

D. Vascular Disorders

- 327 Blood Velocity and Spectra Estimations from Doppler Ultrasound
328 A Program for Evaluating the Dysvascular Patient
330 A Program for Evaluating the Dysvascular Patient (Project Extension)
331 Evaluation of Pressures Applied by Elastic Dressings
332 Postoperative Thromboembolism in Surgical Patients
332 Characterizing Atherosclerotic Lesions by Proton Spectroscopy

XIII. Head Trauma and Stroke

- 334 The Application of Microcomputers for the Treatment of Aphasic Adults
335 Biomechanical Measurements for Quantitative Assessment and Diagnosis of Dysphagia
336 Long-Term Effects of Topical Anesthesia in Stroke Patients: Measurement and Analysis of Neurophysiological Reflexes
337 Development and Evaluation of a Videotape Teaching Module for Nursing Students in the Clinical Setting
337 Computer-Aided Device Evaluation
338 Early Intervention with Globally Aphasic Stroke Patients Using a Computerized Visual Communication Technique
339 Stroke Clinical Center Grant: Remediation of Left-Sided Neglect
339 Treatment of Affective Deficits in Stroke Rehabilitation
340 Rehabilitative Software for Head Trauma Victims
340 Subthreshold Memory Phenomena
341 Precursors of Stroke Incidence and Prognosis
341 Sensorimotor Interactions in Motor Unit Control
342 Medication Effects on Attention and Arousal

XIV. Geriatrics

- 343 Age-Related Changes in Sensorimotor Performance
- 344 Efficacy of Injectable Collagen to Correct Glottal Insufficiency
- 345 Geriatric Prosthetics: Design and Development of an Improved Above-Knee Socket (Project Extension)
- 346 Electromyographic Incontinence Alert Device
- 346 Non-Auditory Factors Affecting Hearing Aid Use in Elderly Veterans
- 347 Integrated System for the Management of Wandering Behavior in the Memory-Impaired Elderly: An Interagency Report
- 348 Work Disability, Disability Management, and the Older Worker
- 349 Perceptual Retention and Age
- 349 Geriatric Medicine Academic Award
- 350 Studies in Idiopathic Normal Pressure Hydrocephalus
- 350 Respite Care for Older Adults: A Prototype
- 351 Epidemiology of Cardiovascular Diseases in the Elderly
- 351 Does Improvement in Mortality Mean Better Health?
- 352 The Community Adaptation of Mildly Retarded Persons: The Lives and Needs of Aging Mentally Retarded Persons
- 352 Learned Modification of Visceral Function in Man
- 352 Senile Dementia: Natural History
- 353 Geriatric Medicine Academic Award
- 353 Falls in the Elderly: Causes and Reduction
- 354 Improving Recovery from Cardiac Surgery
- 354 Cancer Control Science Program: Fox Chase Cancer Center: Cancer Education and Management for Patients
- 355 The Treatment of Acute Illness in Nursing Homes
- 355 Research in Mental Retardation: Elderly Mentally Retarded—Population Description and Service Needs
- 356 Older ESRD Patients: Rehabilitation and Quality of Life
- 357 Illness Cognition and Coping in the Elderly
- 357 Profile of Visual Function in Low Vision Patients
- 358 The Behavioral Context of Incontinence in the Elderly
- 358 Teaching Nursing Home: Modification of Exercise Capacity in the Elderly
- 359 Geriatric Medicine Academic Award
- 359 Geriatric Dentistry Academic Award
- 360 Cutaneous Mechanoreceptor System
- 360 Morbidity Risk Assessment in the Elderly
- 361 Cooperative Group Outreach Program (ECOG)
- 361 Assessment of the Spatial and Temporal Characteristics of Vision as a Function of Age
- 362 Environmental Influences on Behavior of Patients with Alzheimer's Disease

XV. Sensory Aids**A. Blindness and Low Vision****1. General**

- 363 The Use of the Electroretinogram to Predict Retinal Cell Activity
- 363 Pupillary Function in Elderly Individuals with Impaired Night Driving Vision
- 364 Predicting the Visual Abilities of Partially Sighted Persons
- 365 Hearing Impaired Blind Veterans
- 365 A Voice-Output Questionnaire Administrator
- 367 The Physical Correlates of Tactual Perception
- 368 Model-Based Image Enhancement for the Visually Impaired
- 368 Functional Vision and Clinical Tests in Low Vision
- 369 Sonar Sensory Substitution—Spatial Behavior in the Blind
- 369 Electronic Braille Page Output Device Using Nitinol SMA
- 370 Psychophysics of Reading—Normal and Low Vision
- 370 Analysis of Navigation Without Sight
- 371 Profile of Visual Function in Low Vision Patients
- 371 Prediction of Symbol Recognition in Low Vision Patients
- 372 Low Vision Reading: Optimizing Visuo-Motor Performance
- 372 Visual Tests for Patients with Central Scotoma
- 373 Expansion and Enhancement of the National Blindness and Low Vision Database
- 373 An Optimal, Inexpensive Text Entry System for the Orthopedically and Neurologically Disabled
- 374 Time Use and Resource Allocations of People with Visual Disabilities: Assessment Instrumentation
- 375 Development and Validation of a Work Environment Visual Demands (WEVD) Protocol
- 375 A Robotic Hand Communication Aid for the Deaf-Blind
- 377 The Evaluation of Low Vision Aids and Prediction of Visual Performance
- 378 Sensory Aid Technology: A Career Development Intervention Strategy for Blind and Visually Impaired Persons
- 379 Learning Styles and Effective Teaching Technologies for Enhancing the Employment of Deaf-Blind Youth
- 380 Identification of Job Tasks and Management Practices Performed by Blind and Visually Impaired Persons in the Operation of the Business Enterprise Program
- 380 Identification of Work Assessment Technology Needs
- 381 Identification and Classification of the Career Transition Problems of Blind and Visually

- Impaired Persons Employed as Professionals, Managers, or Technicians
- 381 Modification and Adaptation of the Vocational Education Readiness Test for Blind/Severely Visually Impaired Individuals
- 382 Cutaneous Pattern Perception
- 382 Normative Data for Assessing the Manual Dexterity of Visually Handicapped Adults in Vocational Rehabilitation
- 383 Sensory Aids for the Blind and Visually Impaired
- 383 An Improved Volatile Braille Display
- 383 Universal Job Instrumentation System
- 384 Specialized Vocational Aids and Devices
- 385 The Note-a-Braille
- 385 Dotless Braille Reader
- 386 Dexter: A Mechanical Hand for the Deaf-Blind
- 387 Pediatric Research
- 387 Applications of Evoked Potential in Rehabilitation
- 388 Automatic Lens Focusing for the Visually Impaired

A. Blindness and Low Vision

2. Mobility Aids

- 389 Evaluation of Electronic Travel Aids (ETAs) for Visually Impaired Individuals
- 389 Clinical Application Study of Training Techniques and Devices for the Blind
- 390 Measuring the Mobility of Blind Travelers
- 391 Measuring the Spatial Layout Knowledge of Visually Impaired Adults
- 392 Digital Techniques for Objective Analysis of Aural Acoustic Immittance
- 392 Establishing Design/Operational Features for Portable Blind Reading Aids
- 393 A Portable Navigational Aid for Blind Persons

A. Blindness and Low Vision

3. Reading Aids

- 394 Computer Vision to Guide the Blind
- 395 The Human Factors Design of a Large Print Display
- 396 Adaptation of the Amiga Personal Computer to the Visually-Impaired User
- 397 Braille Teaching Aid with Synthetic Speech
- 397 Enhancing the Reading Skills of Low Vision Individuals with Macular Loss
- 398 Software Development: Blissbook

B. Deafness and Hearing Impairment

- 399 Electroacoustical and Clinical Protocols for Evaluating Assistive Listening Devices
- 399 Development of a Digital Hearing Aid and Computer-Based Fitting Procedure: Phase II
- 401 Perception of Reverberation by the Hearing Impaired
- 401 Direct Measurement of Loudness Recruitment in Hearing-Impaired Veterans

- 402 Direct Measurement of Loudness Recruitment in Hearing-Impaired Veterans (Project Extension)
- 403 Rabbit ERG Responses to White-Noise Modulated Stimuli
- 404 Development of Materials for Computer-Assisted Instruction in Lipreading
- 405 Personal Computer System for Acoustic Measurements
- 406 Threshold Sound Pressure Levels (SPLs) for the ER-3A Insert Earphone
- 406 Effects of Manipulation of the Impedance of the Ear of Normal Subjects on Selected Indices of Auditory Function
- 408 Voice and Speech Findings in Prospective Cochlear Implant Candidates
- 409 Basic Mechanisms and Rehabilitative Strategies for Presbycusis
- 409 Changes in Frequency Organization of the Cochlea During Aging
- 410 An Auditory Prosthesis for Sensorineural Hearing Loss
- 411 Transition Study of Persons with Hearing Impairments
- 412 Technology for Sensory Devices for Deaf and Severely Hard of Hearing People
- 413 Project PALS (Places with Assistive Listening Systems)
- 414 AKL Spatiotemporal Representation in a Tactile Aid for the Deaf
- 414 Speech Perception Studies—Bimodal and Developmental
- 415 Tactile Communication of Speech
- 415 Cutaneous Communication Aids for the Deaf
- 416 Rehabilitation Strategies for the Hearing Impaired
- 416 Reading and Writing Skills in the Congenitally Deaf
- 416 Factors Predictive of Reading and Writing Skills in the Congenitally Deaf
- 417 Development of a Wearable Vibrotactile Aid—Phase II
- 417 The Role of the Haptic System in Communication
- 418 Development of a Cochlear Prosthesis
- 418 Wearable Multipoint Opto-Tactile Transducer for the Deaf or Blind
- 418 Basic and Applied Studies of Tactile Perception

C. Speech Impairment

1. Hearing Related

- 419 Measurement and Prediction of Benefit from Amplification
- 420 Computerized Treatment of Acquired Reading Disorders: Treatment of Alexia and Agraphia
- 421 Acoustic Vowel Measures Following Radiation Therapy to the Larynx
- 421 Language Performance in Cleft Palate Adolescents
- 422 The Use of Microcomputers in Diagnosis and Rehabilitation of Adult Aphasic Individuals

- 423 The Acquisition of Morphological Processes in American Sign Language (ASL)
- 423 Electrically Controlled Talking Tracheostomy Systems
- 424 Speech Transmission Laboratory Reports
- 425 Nonlinear Interaction in Voice Production
- 425 Glottal Source—Vocal Tract Acoustic Interaction
- 425 Speech Technology for the Visually Impaired: The Swedish Perspective
- 425 Relationship Between Changes in Voice Pitch and Loudness
- 426 Long-Term-Average Spectrum Analysis of Phonatory Effects of Noise and Filtered Auditory Feedback
- 426 Some Effects of Cochlear Implantation on Speech Production

C. Speech Impairment

2. Aphasia

- 427 Promoting Generalized Language Use: An Analysis of Treatment Strategies
- 428 An Experimental Analysis of Response Elaboration Training in Aphasia
- 428 Drawing: Its Use as a Communicative Aid with Aphasic and Normal Adults
- 429 Computer-Aided Visual Communication for Severely Impaired Aphasics
- 431 Technology Applications for Aphasia Rehabilitation: Lessons from Sweden, Poland, and The Netherlands
- 432 Efficacy of Remote Treatment of Aphasia by TEL-Communicology
- 433 The Influence of Mode of Stimulation on Naming Performance in Aphasia
- 434 Recovery from Aphasia in Stroke
- 434 Communication in Aphasia and Other Organic Disorders
- 435 Reorganization of Brain Function in Recovery from Aphasia

C. Speech Impairment

3. Other

- 436 Effects of Real-Time Biofeedback on Dysarthric Speech
- 436 Perceptual and Acoustical Characteristics of Tracheoesophageal Voice
- 437 Transparent Access to Sources of Computer-Based Information
- 438 Neuropathophysiology of Speech Motor Impairments
- 439 Structure and Acquisition of American Sign Language

XVI. Miscellaneous

- 440 Report on Phase I and Phase II: An Epidemiological Assessment of Disabled

- Veterans in Guam, American Samoa, and Hawaii
- 441 A Pilot Study on the Efficacy of Injected Cross-Linked Collagen in the Treatment of Symptomatic Glottic Insufficiency
- 441 Augmentative Communication for Intensive Care Unit Patients
- 442 Artificial Intelligence Strategies for Orthopedic Clinical Decision Making
- 443 Evaluation of One-Way Air Flow Valve Prostheses in Decannulation Procedures for Chronic Tracheotomized Patients
- 443 Psychiatric Rehabilitation in Nursing Homes
- 444 Assessment of the Swallow Reflex in Patients with Dysphagia
- 445 Dissemination of Rehabilitation Technologies
- 446 Rehabilitation of Neurogenic Communication Disorders in Remote Settings
- 447 The Relationship Between Visual Perception and Social Perception in Cerebral Palsied Children
- 447 Understanding Spasticity and the Effects of Rhizotomy Surgery
- 448 Design and Validation of a Subject/Instrument Interface to Allow Collection of Selected Pulmonary Function and Selected Metabolic Measures of Children with Cerebral Palsy
- 449 Protective Headwear for Disabled Children
- 449 Monitoring Respiratory Patterns and Their Coordination with Swallowing in Cerebral Palsy
- 450 Effects of Relaxed Breathing and Biofeedback on Bronchospasm in Chronic Asthma
- 451 The Finance of Medical Rehabilitation Services: Interim Report on the Mary E. Switzer Distinguished Research Fellowship in Medical Rehabilitation Finance
- 452 Information Dissemination in Communication, Control and Computer Access
- 453 Industry-Based Employee Assistance Program
- 454 Uses and Potential Uses of Information Technology by Rehabilitation Agencies
- 455 Disability Management and Rehabilitation: An Analysis of Programs, Costs and Outcomes
- 456 Epidemiological Study of Pain
- 457 A Neurosensory Interdisciplinary Research Program: Tactile Stimulator Development
- 457 Development of a Data Management System for the Family Asthma Rehabilitation Program (FARP)
- 458 An Innovative Approach to Continuing Health Care Education
- 458 Assessing the Need for Management of the Neurogenic Bowel in the Pediatric Population
- 459 Longitudinal Study of Public Expenditures for Services to the Handicapped

I. Amputations and Limb Prostheses

A. General

Measurement of Stratum Corneum Diffusional Conductance

Gordon R. Neufeld, M.D.; Joyce M. Whang, B.S. Ch.E.; James E. Baumgardner, M.D.; David J. Graves, Sc.D.; John A. Quinn, Ph.D.

Veterans Administration Medical Center, Philadelphia, PA 19104; Department of Chemical Engineering, University of Pennsylvania, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The helium flux method of measuring skin blood flow requires knowledge of the stratum corneum's resistance to helium flux. We are studying ways of measuring this resistance.

Progress/Preliminary Results—Skin temperature in the range of 32 degrees C to 44 degrees C has two effects on gas-flux blood flow measurements. First, temperature increases blood flow by all methods of measurement. Second, increasing temperature reduces the diffusional resistance of the skin to gas flux, resulting in a curvilinear relationship between gas flux and skin temperature. In the case of oxygen transport, the diffusional resistance to oxygen flux is very high until a temperature of 42 degrees C is reached in the skin. To measure pure skin blood flow using a gas-flux technique requires that the diffusional conductance (Ks) for transport be infinite or be known. In our studies to date, we have stripped the stratum corneum prior to the blood flow measurements to attain conductance.

Currently we are working on approaches to meas-

ure Ks in intact skin. Using a physical model of the skin, we have been able to measure Ks for known membranes. Saran, for example, yields a mean Ks of $1.41 \pm 0.16 \times 10^{-1}$ ml/min/cm²/atm. The model equations used and the measurement technique are applicable to measuring stratum corneum resistance.

Future Plans—We can use the physical model of the skin to measure the Ks of stripped stratum corneum. We can do the analogous experiment on intact human skin and compare the Ks measured.

Publications Resulting from This Research

Skin Blood Flow from Gas Transport: Helium, Xenon and Laser Doppler Compared. Neufeld GR, Galante SR, Whang JM, Devreis D, Baumgardner JE, Graves DJ, Quinn JA. *Microvascular Research* (in press).

Response of Cutaneous Velocimetry to a Temperature Change: Normal and Dysvascular Patients Compared. Neufeld GR, Reilly CA, Galante SR, Roberts AB, Baumgardner JE, Graves DJ, Quinn JA. *Vascular Surgery* (in press).

Gas Flux Through Human Skin: Effect of Temperature, Stripping, and Inspired Tension. Baumgardner JE, Graves DJ, Neufeld GR, and Quinn JA, *J Appl Physiol* 58:1536-1545, 1985.

Skin Blood Flow by Laser Doppler Velocimetry (LDV)

Gordon R. Neufeld, M.D.; Cheryl A. Reilly, R.N., B.S.N.; Joyce M. Whang, B.S. Ch.E.; David J. Graves, Sc.D.; John A. Quinn, Ph.D.

Veterans Administration Medical Center, Division of Anesthesia Research, Philadelphia, PA 19104; Department of Chemical Engineering, University of Pennsylvania, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Laser Doppler velocimetry provides a measure of relative skin perfusion only, and cannot as yet be related to any absolute measure of blood

flow to the skin. The purpose of our studies is to compare LDV measurements of skin blood flow with quantitative perfusion fluorometry and our

helium flux method. The long range goal is to develop methods for relating LDV output to absolute blood flow.

Progress—We tested the hypothesis that the elevation of skin temperature alters the stratum corneum in some physical way resulting in a curvilinear LDV response. We compared LDV response to temperature in intact skin and stripped skin over the range 34 degrees C to 42 degrees C.

Results—The data clearly show that as skin temperature reaches 42 degrees C the LDV measurements are essentially identical for both intact and stripped skin. Similarly, these two curves are re-

markably like the helium flux curves generated in intact and stripped skin. We conclude that heat alters the physical properties of the stratum corneum, which results in both a reduction in diffusional resistance and a change in optical properties. Removal of the stratum corneum linearizes the blood flow response to temperature for both the helium flux and LDV blood flow techniques.

Future Plans—These findings may allow us to develop corrections for these physical changes, and thus yield methods for measuring absolute blood flow directly from LDV or gas flux techniques without skin stripping.

Comparison of Helium Flux, Xenon Washout and Laser Doppler Velocimetry in Skin Blood Flow

Gordon R. Neufeld, M.D.; Stephen R. Galante, B.S., Ch.E.; Joyce M. Whang, M.S., Ch.E.; James E. Baumgardner, M.D., Ph.D.; David J. Graves, Sc.D.; John A. Quinn, Ph.D.

Department of Anesthesia, University of Pennsylvania School of Medicine; Division of Anesthesia Research and Division of Nuclear Medicine, Philadelphia Veterans Administration Medical Center; Department of Chemical Engineering, University of Pennsylvania School of Engineering, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—To compare independent measures of cutaneous blood flow in normal healthy volunteers made with Xenon¹³³ washout, helium flux, and laser Doppler velocimetry. Gas transport techniques, such as Xenon washout and helium flux, yield absolute measures of cutaneous blood flow. Laser Doppler velocimetry provides a measure of relative skin perfusion. Xenon washout and helium flux methods are cumbersome, time-consuming, and require application of stratum corneum diffusional conductance in order to properly analyze the results. Laser Doppler velocimetry is relatively easy to use with commercially available equipment.

Progress/Preliminary Results—All measurements were confined to the volar aspect of the forearm. In a large group of subjects we found that helium flux through intact skin changes nonlinearly with the controlled local skin temperature, whereas cutaneous blood flow measured by helium flux through stripped skin changes linearly with cutaneous temperature over the range 33 degrees C to 42 degrees C. In a second group of six volunteers, we compared Xenon¹³³ washout and helium flux at a skin temperature of 33 degrees C and found an essentially linear

relationship between helium flux and blood flow as measured by Xenon with good correlation ($r^2 = 0.82$). In a third group of subjects, we compared helium flux blood flow (stripped skin) to laser Doppler velocimetric (LDV) measurements at adjacent (intact) skin sites and found a nonlinear increase in the LDV skin blood flow compared to helium over the same temperature range. In addition, we compared the helium flux blood flows measured at different temperatures to published data by other independent techniques.

Implications—We conclude that the nonlinear increase in gas flux through intact skin and of LDV output with increasing local skin temperature reflect more than a change in blood flow: they also reflect a physical change in the stratum corneum, which alters its diffusional resistance to gas flux and its optical characteristics.

Publication Resulting from this Research

Skin Blood Flow from Gas Transport: Helium, Xenon and Laser Doppler Compared. Neufeld GR, Galante SR, Whang JM, Devreis D, Baumgardner JE, Graves DJ, Quinn JA, *Microvascular Surgery* (in press).

Oral Fluorescein in Patients

Gordon R. Neufeld, M.D.; David G. Silverman, M.D.; Andrew B. Roberts, M.D.; Cheryl A. Reilly, B.S.N.
Division of Vascular Surgery, Medical College of Pennsylvania; Department of Anesthesia, University of Pennsylvania School of Medicine; Department of Anesthesia, Yale University School of Medicine; Division of Anesthesia Research, Veterans Administration Medical Center, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project was to determine the feasibility and accuracy of oral administration of fluorescein to patients.

Progress—In a preliminary study of oral administration of fluorescein for perfusion studies in seven patients with peripheral vascular disease (PVD) and two volunteers, we found that higher doses are required (7.5–15 mg/kg) compared to intravenous fluorescein (4–8 mg/kg). Significant disadvantages included the requirement that patients be NPO prior to dosing, since food absorbs the dye; that the fluorescein was distasteful even when administered in orange juice; that it caused a degree of staining of teeth and mucous membranes lasting several hours; and, that it frequently resulted in nausea.

Preliminary Results—Following oral administration,

the uptake time for dye fluorescence index (DFI) measurements was 2–3 hours to determine peak levels in the skin. Thus, the total time for a test was extended over several hours to include preingestion and postingestion measurements. The results cannot be directly compared to those of the intravenous test, which is completed in less than 1 hour, because staining patterns are altered by the additional time available for the orally administered dye to distribute. Oral administration did not prove to overcome skin color; the uptake level in an extremely dark patient proved to be misleading with its low values and healed an amputation below that level.

Implications—This study suggests that higher doses of fluorescein are needed along with a suitable method of oral ingestion. Our studies are not conclusive and further work is needed.

Fluorometric Prediction of Canine Small Intestinal Viability Following Venous Occlusion

Ajit K. Sachdeva, M.D.; David A. Brousseau, B.A.; Steven G. Klein, B.A.; Thelma Vilanueva, M.D.; David G. Silverman, M.D.

Departments of Surgery, Anesthesia and Pathology, Veterans Administration Medical Center; Medical College of Pennsylvania and University of Pennsylvania, Philadelphia PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this study was to compare quantitative perfusion fluorometry (QPF) with clinical criteria to determine whether prediction of small-intestine viability following venous occlusion could be improved.

Progress—Assessments of 19 experimental and 20 control segments were performed in 10 adult mongrel dogs after transiently clamping the mesenteric vein (9 segments) and combined artery and vein (10 segments) for periods varying from 7 to 12 hours. Bowel viability was assessed using clinical criteria (color, mesenteric pulsation, peristalsis) and quantitative uptake of fluorescein measured with a per-

fusion fluorometer, after intravenous injection of sodium fluorescein. All segments were resected 24 hours later and assessed for viability using histopathological criteria.

Results—Six of the experimental segments were deemed nonviable and the remaining 13 viable. Fluorescence levels of experimental segments were compared with those of reference segments. By discriminant analysis, optimum cutoff levels of fluorescence between viable and nonviable bowel were determined. All segments with levels > 15 percent at 2 minutes were viable. Similarly, cutoff levels at 20 minutes yielded identical results.

Implications—QPF has a significantly greater specificity than clinical criteria in identifying viable

bowel. At the same time, it retains a very high sensitivity in recognizing nonviable intestine.

Mechanism Based Treatments for Phantom Limb Pain

Richard A. Sherman, Ph.D.

Veterans Administration Medical Center, Augusta, GA 30910

Sponsor: VA Rehabilitation Research and Development Service (Project #XA314-2RA)

Purpose—This study is a direct outgrowth of our currently VA funded work on mechanisms and causes of phantom limb pain. As part of that work we have shown that burning phantom pain is associated with changes in stump blood flow. A decrease in blood flow predicts an increase in burning phantom pain but not in other descriptors of phantom pain. Cramping descriptions of phantom pain are most closely associated with changes in stump muscle tension and spasms but also appear to have some vascular components. Other descriptions of phantom pain are not related to variations in either stump blood flow or muscle tension. We have also found a relationship between changes in barometric pressure and changes in phantom pain for some amputees. This information has permitted us to propose treatments that are most likely to effect the underlying physiological basis for burning and cramping phantom pain.

We propose to treat four groups of ten amputees each with the same six interventions. The amputees will be grouped by the description of their phantom pain. We will work with those describing their phantom pain as: 1) only burning; 2) only cramping; 3) mixed cramping and burning; and, 4) shooting/stabbing/shocking. Before treatment begins, there will be a 3-week baseline in which each amputee will be interviewed and stump muscle tension and heat outflow patterns will be recorded. We know from our previous work that the three descriptors we propose to concentrate on have different underlying mechanisms so we do not expect our interventions to be equally effective for each group.

The six interventions we propose are those behavioral and chemical treatments we could identify which would be reasonably safe for amputees and

are most likely to correct the problems we identified during previous work. Each amputee will receive each treatment for 1 month unless side effects force withdrawal. Treatment months will alternate with 3-week "washout" periods to permit phantom pain to return to baseline. The treatments will be: 1) topical application of nitroglycerine for mainly venous-side vasodilative effects; 2) Trental to reduce blood viscosity so more blood can reach tissues in the stump having compromised vascular beds; 3) Nifedipine as a calcium channel blocker for its known peripheral vasodilative effects; 4) Cyclobenzaprine for its ability to reduce spasms of local origin without interfering with muscle function; 5) muscle tension recognition and relaxation training for its proven ability to reduce microspasms and tension related to intensification of phantom pain; and, 6) body surface temperature recognition and control training for its ability to help people control vasodilation of peripheral vessels while under stress. With the exception of Trental, treatments will be presented in random order. Trental will always be presented last because its clinical effects can last up to 100 days after the end of treatment.

Subjects will be recorded the same way they were during the baseline at each session to permit objective verification of physiological changes. They will come to the clinic every other week during treatments. At the end of the last treatment, there will be another 3-week baseline. Following the final baseline, the treatment which proved most effective, if any, will be continued for 1 year. Subjects will be recorded at monthly intervals. If no treatments are effective, subjects will still be followed for 1 year but will be recorded at 6 and 12 months.

Oral Fluorescein in Animals

David G. Silverman, M.D.; Debby Kim, B.A.; David Brousseau, B.A.; M. Kim, B.A.; Cheryl A. Reilly, B.S.N. Department of Anesthesia, University of Pennsylvania School of Medicine; Department of Anesthesia, Yale University School of Medicine; Division of Anesthesia Research, Veterans Administration Medical Center, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Progress—The goal of this project was to evaluate oral ingestion as the route of fluorescein administration for assessing skin perfusion. In 10 anesthetized rats, dorsal pedicle flaps were raised to produce graded perfusion; then fluorescein 7.5 mg/kg was administered via oropharyngeal tube.

Results—Quantification of skin fluorescence, performed with the fiberoptic fluorometer 45 minutes after dye ingestion, delineated a significant difference between the perfusion of flap regions that remained viable and those that subsequently became dystrophic ($p > 0.05$). The precision was equivalent to that previously reported after intravenous dye. In addition, the gradual delivery of dye after oral

administration permitted monitoring of slope of uptake and time to peak. Each of these pharmacokinetic parameters delineated a significant difference between viable and nonviable sections. As measures of relative change in fluorescence, they are independent of skin color and thickness.

Implications—This suggests that the oral route actually may improve the accuracy and reliability of quantitative perfusion fluorometry.

Publication Resulting from this Research

Fluorescence and Assessment of Skin Perfusion after Oral Fluorescein. Silverman D, Kim D, Brousseau DA, Kim M, Norton K, Reilly CA, *Surgery*, (in press).

The Use of Quantitative Perfusion Fluorometry to Measure Relative Tumor and Liver Blood Flow after Transient Microembolization

A.K. Thom, M.D.; C.A. Reilly, B.S.N.; C.W. Deveney, M.D.; G.R. Neufeld, M.D.; J.M. Daly, M.D. Department of Surgery and Department of Anesthesia, University of Pennsylvania; Division of Anesthesia Research, Veterans Administration Medical Center, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this study was to determine if quantitative perfusion fluorometry (QPF) could be used to evaluate blood flow distribution in the tumor and the liver before and after hepatic arterial infusion of degradable starch microspheres (DSM's).

Progress—Relative changes in tumor and liver blood flow with transient microembolization are unknown but are critical to devising chemotherapy. QPF was compared to Xenon Washout, an established method for measuring blood flow. Xenon¹³³ was injected intraparenchymally and early clearance rate was used to determine blood flow. QPF was used to measure fluorescein uptake by liver and VX-2 tumors after hepatic artery injection of fluorescein (2mg/kg). Five rabbits were used in each study. Serial studies were done in all rabbits before and

after bolus hepatic arterial infusion of DSM's (10mg/kg).

Results—DSM's produced a significant and transient decrease in hepatic blood flow that was maximal after 25 minutes. DSM's also resulted in proportional increase in tumor blood flow (Tumor/Liver Ratio). Relative hepatic blood flow as measured by QPF correlated with Xenon Washout.

Implications—QPF may be clinically applicable to devising chemotherapy in patients.

Publication Resulting from this Research

The Use of Quantitative Perfusion Fluorometry To Measure Relative Tumor and Liver Blood Flow After Transient Microembolization. Thom AK, Reilly CA, Deveney CW, Neufeld GR, Daly JM, *Journal of Surgical Research*, (accepted for publication), 1987.

Experimental Investigation of Joint Prosthesis Fixation

P.K. Humphreys, M.Eng.; J.F. Orr, Ph.D.; W.V. James, F.R.C.S.; A.S. Bahrani, Ph.D.

Department of Mechanical and Industrial Engineering, The Queen's University of Belfast, Northern Ireland and Rehabilitation Engineering Centre, Musgrave Park Hospital, Belfast, Northern Ireland

Sponsor: *The Northern Ireland Prosthetic Orthotic and Aids Service*

Purpose—The objective of this research project is to investigate the mechanical conditions at interfaces between joint implants and bone. A more comprehensive understanding of these conditions will enable designs of both cemented and cementless prostheses to be improved to extend the expected duration of secure fixation.

Progress—The technique of Photoelastic Stress Analysis is being used to examine stresses in bone cement around typical profiles of hip prosthesis stem.

Preliminary Results—Results have already been obtained for mediolateral-lateral compressive loading and torsional loading is currently being investigated. Cyclic loading of hip prosthesis femoral components is being conducted, using a dedicated electro-hydraulic testing machine to compare the fatigue life

of different designs. The fatigue tests are conducted with the prosthesis supported to represent compromised proximal support and rigid distal support in the bone, as required by DD 91 (1986) of The British Standards Institution.

Future Plans/Implications—The cyclic loading experiments will be extended to examine the mechanical aspects of loosening of hip stems in bone cement. It is proposed that this experimental evaluation can be used to prove stem designs derived from the photoelastic work.

Publications Resulting from This Research

A Preliminary Study of the Effects of Mediolateral-lateral Rotation on Stresses in an Artificial Hip Joint. Orr JF, James WV, Bahrani AS, *Engineering in Medicine* 14(1):39-42, 1985.

The Effects of Hip Prosthesis Stem Cross-Sectional Profile on the Stresses Induced in Bone Cement. Orr JF, James WV, Bahrani AS, *Engineering in Medicine* 15(1):13-18, 1986.

B. Lower Limb

1. General

Automated Fabrication of Prostheses and Orthoses: Evaluation/Demonstration of Roehampton CAD/CAM System

Ernest M. Burgess, M.D.; John A. Sidles, Ph.D.; David A. Boone, B.S.; F.A. Matsen, M.D.; Shirley M. Forsgren; Albert F. Rappoport, CP; Joseph H. Zettl, CP

Veterans Administration Medical Center, Seattle, WA 98108 and Prosthetics Research Study, University of Washington, Seattle, WA 98195

Sponsor: *VA Rehabilitation Research and Development Service (Pilot Proposal A949-PA)*

Purpose—This is a pilot project to evaluate and demonstrate the system for automated prosthetic and orthotic manufacture developed by the Bioengineering Centre of University College London.

Residual limb shapes from ten subjects will be digitized as per Bioengineering Centre specifications for subsequent socket rectification and prosthesis

manufacture. Digitized shapes will be electronically transmitted from Seattle to London via Western Union Satellite link. CAD/CAM prostheses will be shipped from London to Seattle via overnight courier where they will be fitted and evaluated at Prosthetics Research Study.

Automated Fabrication of Prostheses and Orthoses: Development of Prosthetic Socket Rectification Rules

Ernest M. Burgess, M.D.; John A. Sidles, Ph.D.; David A. Boone, B.S.; F.A. Matsen, M.D.; Shirley M. Forsgren; Albert F. Rappoport, CP; Joseph H. Zettl, CP

Veterans Administration Medical Center, Seattle, WA 98108 and Prosthetics Research Study, University of Washington, Seattle, WA 98195

Sponsor: VA Rehabilitation Research and Development Service (Pilot Proposal A950-PA)

Purpose—This is a pilot study for the development of socket rectification rules for automated prosthetic and orthotic manufacture. These rules would be based on all of the surgical, biomechanical, physiological, and traditional prosthetic expertise available, as well as detailed computer graphical and numerical analyses.

Dr. Burgess will oversee anatomical and surgical justification for the proposed rectification rules. Dr. Sidles will provide computer graphical and numer-

ical analyses of proposed rectification rules. D. Boone, A. Rappoport, and J. Zettl will be responsible for prosthetic considerations to be built into the rectification rules. Dr. Matsen will be responsible for biomechanical justification of weight loading patterns on the residual limb, and the effect of the socket shape on stump physiology. The rectification rules will be utilized in trial CAD/CAM prosthetics as an aid to rule development and refinement.

Automated Fabrication of Prostheses and Orthoses: Development of Prosthetic Shape Comparison and CAD Software

Ernest M. Burgess, M.D.; John A. Sidles, Ph.D.; F.A. Matsen, M.D.; David A. Boone, B.S.; Shirley M. Forsgren; Albert F. Rappoport, CP; Joseph H. Zettl, CP

Veterans Administration Medical Center, Seattle, WA 98108 and Prosthetics Research Study, University of Washington, Seattle, WA 98195

Sponsor: VA Rehabilitation Research and Development Service (Pilot Proposal A948-PA)

Purpose—This is a pilot project for the development and use of computer graphics software to display, quantify, compare, and manipulate the shapes involved in automated prosthetic and orthotic manufacture.

Residual limb shapes will be digitized and stored for each of 25 subjects. Various methods of digitizing the residual limb will be investigated. The prosthetic socket shape will be digitized from each subject's definitive prosthesis(es). Definitive prostheses made by different prosthetists may also be compared for similarities and differences. The residual limb shape will be compared using computer graphic techniques, to the definitive prosthetic socket shapes

currently being worn by each subject. The computer will quantify and illustrate the precise manner in which the prosthetist has created the prosthetic socket.

Detailed quantitative analysis of these shapes combined with findings from clinical evaluation of the definitive prostheses will be the basis for first generation rectification rules to be built into CAD/CAM systems for Prosthetics and Orthotics. Further, the software to be developed in this pilot study would provide a means for creating a feedback loop for critically analyzing any developing CAD/CAM system.

The Effect on Gait Using Various Ankle-Foot Devices

Frank L. Golbranson, M.D. and Roy W. Wirta, BSME
Veterans Administration Medical Center, San Diego, CA 92161

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this study is to determine criteria for the prescription of prosthetic ankle-foot devices. The study examines relationships between physical characteristics of amputees and locomotion performances when using different ankle-foot devices on level and nonlevel smooth surfaces. Five different configurations under investigation are: 1) SACH; 2) SAFE; 3) articulated single axis; 4) multi-axis Greissinger; and 5) SEATTLE.

Progress—The collection of test data from 20 below-knee amputees was completed. Testing included seven modes of walking: normal, fast, and slow speeds on a level surface; normal speed on surfaces with lateral incline and lateral decline; and normal speed up and down ramps. The acclivity-declivity angle was seven degrees from horizontal. Bilateral switches registered heel contact and medial and lateral foot contacts. Bilateral electrogoniometers registered knee flexion and extension. An accelerometer pack attached laterally to the prosthesis registered angular accelerations in the anterior-posterior and medial-lateral directions. A gimbal-mounted biaxial accelerometer at the sacro-lumbar area registered the fore-aft and vertical accelerations of the

body. A tachometer measured the forward velocity of the body.

The data treatment is a comparative biomechanic analysis focusing on identifying the interpreting effects of the five different ankle-foot devices on locomotion performances and the relation of these effects to stump dimensions and weight of the subjects. Analytical methods include harmonic analyses of wave forms, multiple regression, and identification of relative anomalies occurring in time and displacements.

Preliminary Results—Preliminary findings suggest that harmonic ratios, determined from the fore-aft and vertical accelerations, discriminate among the different devices. Also, differences in the distribution of higher harmonics in wave forms of the angular accelerations of the prosthesis during stance phase appear to be influenced by the type of ankle-foot device for given body weights and stump dimensions. The challenges to locomotion provided by the nonlevel walking surfaces appear to be useful in comparing and relating compliance characteristics of different ankle-foot devices to stump dimensions and body weights and how these affect the relative quality of gait.

Diabetic Neurotrophic Ulceration: Screening and Prevention Utilizing Aesthesiometry

John J. Holewski, D.P.M.
Veterans Administration Medical Center, San Francisco, CA 94121

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Sensory loss, caused by neuropathy, is a major contributing factor in the development of neurotrophic ulceration in the diabetic lower extremity. A noninvasive screening test for evaluating the extent of sensory loss in diabetic peripheral neuropathy is needed. New diagnostic criteria from such a screening test may be helpful to predict the relative risk of development of neuropathic foot ulceration in the diabetic population. The aim of this work project feasibility study was to develop a testing method utilizing Semmes-Weinstein pressure

aesthesiometry probes and evaluate the technique's ability to quantify sensory loss in the lower extremity of diabetic patients.

Progress—The best sites on the foot to test and which range of probes to use were determined. A technique was devised to reduce subjectivity in collecting data by applying pressure only at random intervals and eliciting the patient's response. Using this method of applying the probes we determined the cutaneous pressure sensation threshold for var-

ious sites on the foot. These sites included areas prone to pressure ulceration and are representative of various peripheral nerves and dermatomes of the foot. Initial reproducibility trials were conducted on ten control subjects and a sensitivity threshold level was determined by selecting the smallest filament with at least two correct interval responses in a triplicate repetition set. Over 200 patients, both diabetic and nondiabetic, have been tested utilizing this technique. Our aim was to obtain cutaneous pressure thresholds for comparison of four different groups of patients: nondiabetic subjects; nonneuropathic diabetic subjects; neuropathic diabetic subjects without a history of pedal ulcerations; and, diabetic subjects with a history of pedal ulcerations.

Results—Cutaneous pressure sensation is measurable in the foot and values are reproducible. Decreased cutaneous pressure sensation does correlate with ulceration and clinical neuropathy. The technique is sensitive for identifying patients with a sensory deficit in peripheral neuropathy. Additionally, the technique appears very specific which may make it ideal to help differentiate which patients may be at risk for ulceration. The best discrimination

between groups is obtained by requiring that three of the six plantar forefoot sites have a sensitivity threshold level of greater than 5.07 log(0.1mg) force as the risk discriminator level.

Future Plans/Implications—As a direct result of this feasibility study, recommendations have been made to prospectively test the ability of this technique to identify high risk diabetic patients. Such a long-term study is under way. This technique also needs to be compared with other sensory testing methods (thermal sensitivity and vibratory testing) to determine which offers the best sensitivity, specificity, and accuracy in relation to ulcer formation. Now that effective quantitative methods are available, there is a need to correlate this information with other risk factors (i.e., duration of diabetes; structural and vascular status of the foot) to determine relative risk.

Publications Resulting from This Research

Aesthesiometry: Quantification of Cutaneous Pressure Sensation in Diabetic Peripheral Neuropathy. Holewski et al., (accepted for publication) *Journal of Rehabilitation Research and Development* 25(2), Spring 1988.

Limb Viability: Vascular Reconstruction and Amputation Surgery

James M. Malone, M.D.; Robert E. Henry, M.D.; Kenneth C. Mylrea, BSEE, Ph.D., WOC
Maricopa Medical Center, Phoenix, AZ 85010

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The plan of this research project is to develop techniques for preoperative amputation level selection, to develop techniques for assessment of limb viability after major vascular reconstruction, and to evaluate the role of education for the prevention of amputation in high risk, diabetic patients.

Progress—Studies on amputation level selection and limb viability have been done by prospective comparison by transcutaneous oxygen, transcutaneous carbon dioxide, intradermal Xenon¹³³, and Doppler systolic blood pressures and ankle/brachial indices.

Assessment of limb viability during and after major vascular reconstructive surgery has been done in a prospective fashion utilizing transcutaneous oxygen, transcutaneous carbon dioxide and Doppler systolic blood pressures.

The diabetic education program has been a prospective educational system. All patients admitted to the hospital with complications of diabetic foot problems including ulceration, infection, or prior toe or limb amputation have been entered into the study. Patients were randomized into an educational or non-educational group based upon the odd or even characteristic of the last digit of their Social Security number. An educational program under the organization of physicians, but designed to be nurse run, was provided to those individuals in the educational arm. This program lasts approximately one hour. All patients were treated the same with respect to their medical care and follow-up. The primary purpose of the study was to assess what, if any, was the impact of an educational system on the long term complications of diabetic foot problems.

Results—The results of the prospective amputation level selection study have recently been published in the August, 1987 issue of the *American Journal of Surgery*. The metabolic parameters were highly statistically accurate at all levels of lower extremity amputation and were clearly superior to intradermal Xenon¹³³ and Doppler pressures or Doppler-derived

indices.

The data from the diabetic educational program is still being compiled and reviewed but there was a decrease in the incidence of subsequent limb amputation from 18 percent to 6 percent in comparing the non-education to the education group.

Identification of Optimal Amputation Level in Ischemic Limbs

Norah Milne, M.D., Ch.B.

Veterans Administration Medical Center, Long Beach, CA 90822

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This research project is intended to characterize perfusion in ischemic lower limbs at rest and during hyperemia following temporary arterial occlusion. The goal is to identify the level at which the amputation site will heal well, while preserving the longest possible stump in patients with peripheral vascular disease. Perfusion will be evaluated using two methods: 1) Thallium-201 scintigraphy with computer and tomographic gamma camera; and 2) Thallium-201 scintigraphy with small silicon avalanche detectors (SADs) applied to the skin above and below the knee and on the foot. The use of the SADs will allow evaluation of skin perfusion only. Additional data will be obtained from transcutaneous

oxygen probes and Doppler ultrasound.

Progress—Five inpatient subjects with peripheral vascular disease have been scheduled for study thus far. These patients will be studied prior to and after their scheduled amputation. The site of amputation will be selected on clinical grounds and will not be influenced by the experimental data.

The outcome of the amputation will be compared with the experimental data described above. Additional data will be obtained for normal subjects and diabetic subjects without medical indication of amputation.

Quantitative Perfusion Fluorometry As a Useful Adjunct to Determine the Healing of Lower Extremity Amputation

Gordon R. Neufeld, M.D.; Andrew B. Roberts, M.D.; Cheryl A. Reilly, B.S.N.; Kalind R. Bakshi, M.D.; David G. Silverman, M.D.

Division of Vascular Surgery, Medical College of Pennsylvania; Department of Anesthesia, University of Pennsylvania School of Medicine; Department of Anesthesia, Yale University School of Medicine; Division of Anesthesia Research, Veterans Administration Medical Center, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Adequate nutritive blood flow is the primary requirement for the healing of amputations. We have developed a multidisciplinary approach to the measurement of skin blood flow and the clinical evaluation of these patients. Our purpose is to maximize the patient's rehabilitative potential by performing the amputation as distally as possible through the use of quantitative perfusion fluorometry (QPF) preoperatively to predict healing.

Progress—This report outlines our progress using quantitative perfusion fluorometry in the evaluation of cutaneous blood flow preoperatively in patients with peripheral vascular disease and diabetes mellitus who are undergoing amputations.

In this study, 130 patients underwent QPF before undergoing 145 amputations, and preoperative predictions of amputation healing were made based on fluorescein levels. If the proposed amputation site

had more than 42 percent of the fluorescence of an upper extremity reference site, healing was predicted. If the relative fluorescence was less than 38 percent, amputation failure was predicted. The test was not predictive if the leg was edematous, cellulitic, or had abnormally thickened or hyperpigmented skin. Eight amputations were excluded because the extremities had one of these characteristics. Of the remaining 137 amputations, 9 had a dye fluorescence index of less than 38 percent, and all

failed: 117 amputations had ratios greater than 42 percent and of these, 102 (87 percent) healed. The test had a sensitivity of 100 percent, a specificity of 37 percent, and a predictive value of 88 percent.

Implications—We conclude that QPF is a useful adjunct to the clinical judgment of the surgeon when attempting to optimize a patient's rehabilitative potential, while avoiding amputation failure.

Determination of Causes and Mechanisms of Phantom Pain

Richard A. Sherman, Ph.D.; Glenda M. Bruno, R.N., M.S.; Jeffrey L. Ernst, Ph.D.; Roberto Barja, M.D.
Eisenhower Army Medical Center, Fort Gordon, GA 30905 and Veterans Administration Medical Center, Augusta, GA 30910

Sponsor: VA Rehabilitation Research and Development Service; Department of Clinical Investigation of the US Army

Purpose—The purpose of this study is to determine the causes and mechanisms of phantom pain.

Progress—Amputees reporting stump and/or phantom limb pain were recorded using thermographic measures of near-surface body heat and surface electromyographic measures of muscle tension. Each subject was recorded between two and four times while reporting varied pain intensities. Thermographs showing heat patterns were taken of veterans diagnosed as having complete and incomplete spinal cord injuries (SCIs). Each subject used a body map to identify areas with phantom, no, and normal sensations. Amputees kept a year long daily log of environmental factors and intensity of phantom pain in order to identify factors related to changes in phantom pain. Veteran amputees were surveyed about the impact of phantom pain on their lives and other topics.

Preliminary Results— *Physiological mechanisms.* Among amputees, a consistent inverse relationship between intensity of pain and stump temperature relative to the intact limb occurred for burning, throbbing, and tingling descriptions of phantom limb pain and stump pain, but not for other descriptions. There is no convincing evidence that major personality disorders are important in the etiology of chronic phantom pain. Initial evaluation of logs indicates that phantom limb pain can be effected by the external environment.

Among SCI subjects, there was an almost exact

correlation between the location of phantom sensations drawn on the body maps and relatively warm areas on the body. Subjects with complete SCIs showed a temperature gradation between a normally sensate upper level and a lower level in which sensations were either absent or different from pre-injury sensations that were not present among subjects with incomplete SCIs.

Impact of phantom pain on activities. Data from surveys and logs indicates that phantom pain prevents one fifth of those respondents who want to work from working and seriously interferes with the work of a third of those who are employed. Weekly sleep loss and forced withdrawal from interesting social activities is typical.

Future Plans/Implications—We are testing treatments based on mechanisms identified to date and will continue searching for the causes of other descriptors of phantom pain. Our results indicate that there may be pathways for pain outside the spinal cord.

Publications Resulting from This Research

What to Expect When You Lose a Limb. Barja R, Sherman R, GPO Publication #008-020-01083-9, 1986.

Application of Recent Discoveries of Physiological Bases for Phantom Limb and Phantom Body Pain to Chronic Pain Mechanisms and Treatments. Sherman R, Ernst J, Barja R, Bruno G, *Medical Bulletin of Europe*, November, 1986.

Concurrent Variation of Burning Phantom Limb and Stump Pain with Near Surface Blood Flow in the Stump. Sherman R, Bruno G, (accepted for publication) *Orthopedics*, 1987.

Psychological Factors Influencing Chronic Phantom Limb Pain. Sherman R, Sherman C, Bruno G, *Pain* 28:285-295, 1987.
Relationships Between Near Surface Blood Flow and Altered Sensations Among Spinal Cord Injured Veterans. Sherman R, Ernst J, Markowski J, *American Journal of Physical*

Medicine 65(6):281-297, 1986.
Differences Between Trunk Heat Patterns Shown by Complete and Incomplete Spinal Cord Injured Veterans. Sherman R, Ernst J, Markowski J, *Paraplegia* (in press).

Development of a Sensory Substitution System for the Insensate Foot

Jacqueline J. Wertsch, M.D.; Paul Bach-y-Rita, M.D.; Melvin B. Price, D.P.M.
Veterans Administration Medical Center, Milwaukee, WI 53193

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Diabetics frequently have insensate feet, which leads to improper gait, excessive pressure loading, breakdown of tissue, infection, and amputation. We will develop a system of seven sensors under each sole and feed back the information on distribution of pressure to the subject through an electrotactile display around the waist. This sensory substitution system should partially restore sensation and reduce excessive pressure loading.

Progress—A conference with our research team and four consultants resulted in an increased emphasis on using leather extra depth shoes rather than sandals fabricated from foam, and obtaining pressure data from the soles during normal and altered gait. The engineering members of the team are John G. Webster, Ph.D. and Willis J. Tompkins, Ph.D., Department of Electrical and Computer Engineering, University of Wisconsin. They have surveyed possible sensors that will fit into the shoe insole, selected the Interlink conductive elastomer sensor, installed seven sensors in each insole, and developed a calibration setup. The present system obtains data at a 35 Hz rate over a full-scale range of 870 kPa with a resolution of 29 kPa from a subject who walks at the end of an umbilical cord. They have written a program to acquire the data and display it as bar graphs in real time and also pressure versus time after postprocessing on an IBM PC.

Results—Tests during normal walking at 96 steps/

minute show a peak pressure of 638 kPa under the right first metatarsal head and 551 kPa under the great toe. Tests during altered gait caused by elevation of the left foot show a shift of peak pressure to the right great toe and an increase at 5 cm elevation to 678 kPa. Tests with a 5.4 kg weight in the right hand increased the right great toe pressure to 667 kPa. Also, the time from heelstrike to pushoff changed from normal values of left:857 ms, right:914 ms to altered values of left:771 ms, right:971 ms.

Future Plans/Implications—The engineering team will evaluate alternative sensors such as capacitive sensors, metal strain gauge sensors, and electro-optical sensors. They will develop a portable system that will be worn on the belt to acquire data from an ambulatory subject. This will dump stored data into the IBM PC for analysis and replace the umbilical system. They will program the portable system and perform tests on ambulatory subjects. The medical team will analyze the data and suggest modifications to the data-gathering system. They will analyze results from patients with normal and abnormal sensation to investigate how pressure distribution varies as a function of walking time. After acquiring baseline data, we will determine the optimal method of translating sensor data to provide feedback to the patients through an electrotactile display. We will then design a complete system and test it on patients to determine its potential for reducing foot problems.

Novel Pace Counter Design for Lower Limb Temporary Prostheses

Sohrab Kourosh, Ph.D.; Frank Gottschalk, M.D., F.R.C.S. Ed.; John Potter, C.P.O.

Division of Orthopaedic Surgery, UTHSCD, Veterans Administration Medical Center, Dallas, TX 75216

Sponsor: *Dallas Veterans Administration Medical Center*

Purpose—Experience has shown that early weight-bearing following amputation will have a positive effect on the healing and maturation of the stump. This helps shorten the rehabilitation period and also allows for a more successful fitting of the permanent prosthesis. If the amputee can successfully wear and use the temporary prosthesis at home, the in-hospital supervised rehabilitation period and cost can be considerably reduced.

Progress—In order to aid this process, and to help assess the patient's own rehabilitative efforts, a pace counter has been developed. In addition, the pace counter has been used to help assess whether a patient is a suitable candidate for prosthetic rehabilitation. The pace counter is a simple device which

counts the number of gait cycles performed, above a specified load threshold, between visits to the rehabilitation center. The pace counter characteristics include fitting within the pylon of the temporary prosthesis; minimal displacement and weight so that it does not interfere with normal functioning of the prosthesis; adjustable threshold load to conform with the patient's weight and count only the full weightbearing portion of the gait cycle. In addition the counter is self-contained and is insensitive to lateral loading. A counter display is readable by the patient, allowing "visual feedback" to encourage prosthetic use. This design enables the patient to set and achieve self-determined goals and to shorten the stump healing and consolidation period.

A Rehabilitation Shoe for the "At Risk Foot"

Sohrab Kourash, Ph.D.; Mel Stills, M.D.; Vert Mooney, M.D.; Frank Gottschalk, M.D., F.R.C.S. Ed.

Division of Orthopaedic Surgery, UTHSCD and STAMP Program, Veterans Administration Medical Center, Dallas, TX 75216

Sponsor: *Dallas Veterans Administration Medical Center*

Purpose—The "at risk foot" is defined as the neurologically deficient, partially ischemic foot that is prone to ulceration and infection secondary to diabetes, neurological deficits, ischemia, and post-traumatic deformity. Edema and impaired blood supply, combined with deformity and lack of sensation; cause the weight-bearing forces to magnify and produce destructive lesions. Application of a total contact cast has been shown to provide satisfactory results in promoting the healing of chronic ulceration and the mechanically induced inflammation in the "at risk foot." The high cost of this treatment, the difficulty of maintaining hygiene inside the cast, the lack of adjustment with the edematous foot, and patient discomfort during sleep and rest, makes the application of the total contact cast cumbersome.

Progress—A rigid total contact shoe insert used in conjunction with a short leg walking brace will provide the same favorable pressure distribution, without the undesirable characteristics of the total contact cast. This is confirmed by using recently developed equipment (EDG) which is able to dynamically measure gait parameters and foot support interface pressures. The same rigid insert used in conjunction with an extra depth orthopedic shoe will allow even distribution of the interface pressure, and prevents shear loading and friction. With appropriate understanding of the force distribution on the plantar surface of the foot, a combination of an extra depth shoe and a properly designed rigid total contact insert should provide a long-term solution for protection and rehabilitation of the "at risk foot."

Objective Assessment of the Performance of Insert Materials in Diabetic Footwear

Sohrab Kourash, Ph.D.; J. Brodsky; Mel Stills, M.D.; Vert Mooney, M.D.; Frank Gottschalk, M.D., F.R.C.S. Ed.
UTHSCD and STAMP Program, Veterans Administration Medical Center, Dallas, TX 75216

Sponsor: *Dallas Veterans Administration Medical Center*

Purpose—The use of interface materials for the protection of the "At Risk Foot" from the excessive loading and shocks generated during walking is important in the prevention and treatment of pressure ulcers. These interface materials are used as orthotic shoe insoles because of their characteristics for pressure distribution, shock absorption, and elastic properties. Within the confines of a shoe, the inserts are subjected to sustained deforming deflection, cyclic compression, and cyclic shear compression loading. These forces gradually deform the shape of the insert and progressively decrease the functional properties, so that the insoles lose their beneficial function and even become harmful.

Progress—Five commonly used interface materials were tested in the laboratory. Plastazote, Pelite, PPT, Spenco and Sorbothane were evaluated for

any change and ability to absorb shock, distribute pressure, and deformation, under the previously mentioned loading situations.

Preliminary Results—The least deformation was in the PPT and the maximum in the Plastazote which has the best pressure distribution. We are currently recommending a combination of a PPT base with a Plastazote cover as shoe inserts and are further studying these materials in a clinical situation, using a modified electrodynograph system.

Future Plans/Implications—The foot ground interface pressure is measured at biweekly intervals. The use of this combination of materials appears to provide the best type of insole with the least amount of deformation and least change of pressure distribution and shock absorption.

Design Modification to the Metatarsal Break of the SACH Prosthetic Foot

Paul Allard, Ph.D., P.Eng.; Hubert Labelle, M.D.; Gilbert Drouin, Ph.D., P.Eng.
Pediatric Research Centre, Hospital Sainte-Justine, Montreal, Quebec H3T 1C5, Canada

Sponsor: *National Health Research and Development Program and the War Amputees of Canada*

Purpose—Prosthetic feet for children represent scaled-down versions of the adult models, which do not necessarily meet the requirements of the active child. The Solid Ankle Cushion Heel (SACH) foot is the component most widely used by lower limb amputees in North America and has not evolved significantly since its conception in the 1950's. Recent studies of unilateral below-knee child amputees reveal significant gait asymmetry due to lack of an active plantar flexion moment during push-off. The objective of this study is to modify the design of the SACH foot to include a leaf-spring component at the metatarsal break, to impart an adequate resisting moment on the prosthesis during toe-off, while still allowing dorsiflexion of the toe region.

Progress—To determine the mechanical character-

istics of the new component, the prosthesis will be modeled as a system of mass, spring, and dashpot elements. A mathematical relationship will then be derived relating the angle of deflection, angular velocity and accelerations of the shank to the ground and knee-reaction forces, knee moment, and mechanical properties of the system. The spring and damper characteristics will be determined by an optimization technique and the modification of the actual prosthetic foot will be carried out implementing these parameters. The mechanical properties of the prosthesis will be verified by means of a bench test using a tensile machine. The kinematic and kinetic parameters (from a gait analysis of two unilateral-BK child amputees wearing the newly designed prosthesis) will be carried out to validate the model.

Comparison of Feedback Controllers for Functional Neuromuscular Stimulation

P.E. Crago, Ph.D., and Howard J. Chizeck, Sc.D.
Case Western Reserve University, Cleveland, OH 44106

Sponsor: *National Institutes of Health*

Purpose—The purpose of this project is to compare quantitatively the properties of three previously designed single-degree-of-freedom feedback controllers for regulating the input/output properties of stimulated muscle systems. The three discrete time digital controllers are: a) a first order fixed parameter pulse width modulation controller; b) an adaptive parameter pulse width modulation controller; and c) a combined pulse width and stimulus period controller. The first controller has the advantage that it is extremely easy to implement in terms of computational overhead and has been found to be quite robust to changes in muscle recruitment gain. The second controller has the advantage that it can adapt to a much wider range of changes in muscle properties without a degradation of response parameters. The third controller has the advantages of the fastest response time and the ability to modulate stimulus period to increase the range of force production. The last two controllers have the disadvantage that they require an order of magnitude more computation time than the first controller.

Progress—Each of the controllers has been implemented in software that allows trial by trial comparison. The controllers regulate the stiffness at the ankle joint of cats by stimulation of two antagonists. The tibialis anterior and gastrocnemius muscles are implanted with coiled wire intramuscular electrodes and are chronically stimulated to convert their met-

abolic and physiological properties to those of slow, fatigue resistant muscles. At two-week intervals the animals are anesthetized for acute experiments to evaluate the controllers. The leg is mounted in a frame to allow a servo-controlled torque motor to provide a variable external load at the ankle. The controllers are being evaluated in terms of the temporal response parameters for step and ramp inputs (i.e., rise time, overshoot and settling time) and in terms of the mean absolute and mean squared error. Detailed tuning criteria are also being developed for each controller.

Loading conditions are designed to simulate the control of functional tasks. Performance is important in: a) unloaded position control (e.g., prior to contact in grasp or position control at the elbow, wrist or hip); b) isometric force control (grasping of a rigid object); c) combined position and force control (grasping of a compliant object); and d) during load transitions (the changes in load that take place when a limb comes into contact with external objects).

Preliminary Results—The expected outcome is that one controller will not meet all needs in control of stimulated muscle. The results of the present project will provide a quantitative assessment of distinctly different controllers under a wide range of conditions that are encountered in functional neuromuscular stimulation (FNS) and will form the basis of choosing among them for specific applications.

Management of Tarsal Disintegration in Leprosy

V.N. Kulkarni, B.Sc.(PT)PGDR; S.B. Sane, M.S.; R.C. Sharangpani, M.S. Dip. Sports Medicine;
J.M. Mehta, M.B.B.S.

Dr. Bandorawalla Leprosy Hospital, Kondhawa, Pune 411022, India

Sponsor: *Poona District Leprosy Committee*

Purpose—Tarsal disintegration (TD) is well known among leprosy workers. It occurs exclusively in a neuropathic foot of leprosy and can be described as a process where the tarsal bones undergo a series

of slow and progressive changes, losing their anatomical configurations to each other and, ultimately, leading to destruction and disorganization.

The normal intrinsic and extrinsic musculature

which supports the arches of the foot, which form a base for human propulsion and help to distribute forces during static and dynamic phases of gait, get paralyzed in leprosy. The ligaments, which are intact initially, also eventually are involved. This results in a disturbed weight transmission/distribution of forces in addition to a sensory deficit. The bones also undergo pathological changes since they are subjected to stress and strain. Normal compression and shearing forces during the heel-toe pattern are altered due to sensory deficit, muscular paralysis, and ligamentous laxity, making the neuropathic foot more vulnerable to destruction.

In its early stages, disintegration takes the form of swelling and raised temperature round the ankle joint with or without pain or collapse of arch. In the late stages, fixed deformities occur that are complicated by the presence of ulcers and secondary osteomyelitis. Radiologically, the earliest changes can be detected in the form of localized osteoporosis, cystic cavities with minimal fractures; advanced changes are extensive fractures, flattening of bones, and separation of hind and fore foot with effects of osteomyelitis and presence of sequestrae. Conservative treatment of TD has been rare, even though the process of TD itself has been studied extensively. Amputation is still the only treatment left in patients who report with an advanced case of TD. This could be attributed to the fact that early diagnosis is still not prevalent. The purpose of this study was to achieve an early diagnosis and non-radical treatment.

Progress—Fifty cases were studied and treated un-

der the following principles: 1) absolute rest and control of infection, if any; 2) plaster immobilization after thorough clinical and radiological evaluation till the lesion is healed; 3) strengthening of both diseased and normal lower extremities by physical therapy to maintain flexibility in the other joints; 4) graded weightbearing after the lesion is healed, which helps spatial reconstructing of bony trabeculae that are weakened in the process of TD; 5) amputation with proper prosthesis in advanced cases; 6) rehabilitation through a) prescription of Fixed Ankle Brace (FAB) and other appliances; b) modification of strenuous occupational conditions; c) care of anaesthetic feet; and d) proper health education.

Results—This study showed that increased and abnormal shearing forces occurring during the heel-toe pattern were the main causative factors both in occurrence and progression of TD. This has also been proved by a negative finding in another study conducted on patients having short feet wherein the typical changes of TD were not observed. (In short feet the heel-toe pattern is abolished, ultimately reducing the shearing forces, and the chances of getting TD.) Treatment after the lesion is stabilized, is thus aimed at reducing these forces by a FAB appliance. This appliance controls the ankle movements because its rocker action reduces the shearing forces. The process has been well controlled in patients using this appliance. These patients were followed up every 6 months to assess the efficacy of conservative treatment.

The Effect of Plantarflexion Bumper Stiffness in Single-Axis Prosthetic Feet

Sanford H. Anzel, M.D.; Thay Q. Lee, M.S.; Edmond Ayyappa, C.P.O.
Veterans Administration Medical Center, Long Beach, CA 90822

Sponsor: *Special Team for Amputations, Mobility, Prosthetics/Orthotics (STAMP)*

Purpose—In lower extremity amputee prosthetic gait, the normal physiological plantarflexion motion may be simulated by the use of a foot prosthesis with an articulating ankle, such as a single-axis prosthetic foot. In a single-axis foot mechanism, the rate of plantarflexion is predominantly dependent on the compressive stiffness of the plantarflexion

bumper and the weight of the patient. However, the quantitative parameters of these bumpers are not readily available through the manufacturers, and commercially available bumpers do not cover an adequate range of stiffness required for a variety of patients. Currently, the criteria used for selecting a plantarflexion bumper is acquired through the

prosthetist's experience. Therefore, the objectives of this study were to quantitatively assess the compressive stiffness of the plantarflexion bumpers and also to provide a guideline for the prosthetist in choosing a plantarflexion bumper with correct compressive stiffness to obtain a symmetric bilateral gait pattern.

Progress—For the first objective, an Instron Material Testing System was used to determine compressive stiffness of 6 commercially available and 4 modified plantarflexion bumpers. For the second objective, unilateral below-knee amputees (BKA) were subjected to ambulation with single-axis foot prostheses. Ten plantarflexion bumpers with a spectrum of compressive stiffness along with a Footswitch Stride Analyzer System (B&L Engineering, Santa Fe Springs, CA) were used to produce and evaluate gait pattern. The parameters provided by a Footswitch Stride Analyzer System include velocity, cadence, limb support time, and the loading pattern of the foot.

Preliminary Results—The compressive stiffness of 10 plantarflexion bumpers (6 commercial, 4 modified)

ranged from 2.0 N/mm to 4.1 N/mm. This spectrum of compressive stiffness proved to be adequate for satisfying unilateral BKA subjects with a single-axis prosthetic foot. Once the highest degree of symmetry in gait pattern was obtained, the compressive stiffness (K) of the plantarflexion bumper was plotted with respect to the body weight (B) of the amputee and the relationship was found to be linear ($K = 0.077B - 3.167$, $r = 0.90$).

Future Plans/Implications—Future plans are to evaluate all commercially available plantarflexion bumpers to assess their feasibility and durability, since the prescription of a single-axis foot prosthesis requires the selection of an appropriate plantarflexion bumper in order for the patient to ambulate effectively. Selection is based on the type of single-axis foot prosthesis, body weight of the patient, activity level, and gait characteristics. This study quantifies the compressive stiffness of commercially available plantarflexion bumpers, and its linear relationship with the body weight of the patient for symmetric bilateral gait pattern. Thereafter, the prosthetist can use observational gait analysis skills and patient feedback to finalize the prosthesis.

Gait Lab Analysis of Dynamic Elastic Response in Prosthetic Feet

Edmond Ayyappa, C.P.O.; Richard Chambers, M.D.; Leslie Torburn, M.S., P.T.; Jacquelin Perry, M.D.; Thay Q. Lee, M.S.

Rancho Los Amigos Medical Center, Pathokinesiology Department, Downey, CA 90242 and Veterans Administration Medical Center, STAMP (117S), Long Beach, CA 90822

Sponsor: *Special Team for Amputations, Mobility, Prosthetics/Orthotics (STAMP)*

Purpose—"Dynamic Elastic Response" is defined as the spring-like elastic characteristic recently being incorporated into the componentry and design of prosthetic feet which presumably improves the physiological function of walking. This project examines and compares the mechanical and physiological differences of recently introduced "Dynamic Elastic Response" (DER) prosthetic feet for below-knee and above-knee amputees. Seven below-knee amputees and seven above-knee amputees will each be fitted with a variety of "DER" type prosthetic feet as well as a control foot, the SACH foot.

A period of accommodation of one month for each foot ensures that each prosthesis is truly functional for daily activities and permits the am-

putee to accommodate to the particular characteristics of each foot before testing. Looking at footswitch stride data, intramuscular EMG's, coronal and sagittal vectors and torques, and joint motion, the study seeks objective analysis and gait lab confirmation of this presumed "Dynamic Elastic Response." A questionnaire will record the amputees' subjective assessment of five different prosthetic feet and any correlation of the gait lab data will be noted.

Progress—Five of a total of 14 amputees were selected and had begun the testing. All subjects maintain the same prosthetic socket throughout the testing. All prostheses are aligned for normal walking

cadence, not running. Subjects are community ambulators who can walk 50 m/min for a minimum of 20 minutes without cane, crutch, or other assistive devices and who incorporate knee flexion in their loading response. Above-knee subjects have been fitted with hydraulic knees, since clinical reports have indicated their compatability with DER feet. With regard to the below-knee amputee, we have observed interesting early trends for the Flex-foot which should demonstrate statistical significance with the inclusion of all subjects. The interdependent gait characteristics of velocity, cadence, and stride have been closer to normal values than with either the SACH or Single-axis foot, regardless of the density and compression of the bumper or heel cushion used. The prosthetic ankle torque has thus far not followed normal patterns as closely as the

SACH or Single-axis foot but the physiological joint torques of hip and knee have been thus far remarkably closer to normal torques than with the SACH or Single-axis foot.

Future Plans—A detailed biomechanical analysis of the SACH foot has been performed by Inman and his investigative team which resulted in the refinement of prescription parameters and the development of alignment guidelines for the use of the SACH foot. The data from this study will serve as the raw material for the development of such guidelines for DER prosthetic feet. A paper describing our project was presented at the American Orthotic and Prosthetic Association Annual National Assembly in September, 1987.

Energy Cost Comparison of "Stored Energy" Prosthetic Feet with Solid Ankle Cushion Heel Prosthetic Feet

**Richard Chambers, M.D.; Edmond Ayyappa, C.P.O.; Leslie Torburn, M.S., P.T.; Jacquelin Perry, M.D.;
Thay Q. Lee, M.S.**

Rancho Los Amigos Medical Center, Pathokinesiology Department, Downey, CA 90242 and Veterans
Administration Medical Center, STAMP (117S), Long Beach, CA 90822

Sponsor: *Special Team for Amputations, Mobility, Prosthetics/Orthotics (STAMP)*

Purpose—Since energy conservation in prosthetic gait is a crucial element in the rehabilitation of all amputees, there is a particular need to quantify energy expenditure of amputees while using the recently introduced "energy storing" prosthetic feet. This study will monitor the relative oxygen consumption of above-knee and below-knee amputees as they ambulate on commercially available "stored energy" type prosthetic feet of various designs. The study will compare those findings with data obtained when the same subjects walk with the current prosthetic standard, the Solid Ankle Cushion Heel (SACH) prosthetic foot. Seven below-knee amputees and seven above-knee amputees will each be fitted with a variety of "stored energy" type pros-

thetic feet as well as a control foot, SACH. A period of accommodation of one month for each foot ensures that each prosthesis is truly functional for daily activities and permits the amputee to accommodate to the particular characteristics of each foot before testing. Feet to be tested include the Seattle Foot, Flex-foot, Stenfoot, Carbon Copy Foot, and possibly others.

Progress—Preliminary results are expected by December, 1988. Presentation of the data on several of the initial subjects being tested was presented as case histories at the American Academy of Orthotists and Prosthetists combined annual meeting with COPA/AOPA during June, 1987.

B. Lower Limb

2. Below-Knee

Prosthetics Research Study Report

Ernest Burgess, M.D.

Veterans Administration Medical Center, Seattle, WA 98108 and Prosthetics Research Study, University of Washington, Seattle, WA 98195

Sponsor: *VA Rehabilitation Research and Development Service*

Progress—During the past year and a half, the Seattle Foot has become commercially available. At this time (August 1, 1987) approximately 14,000 feet are now being worn by veterans and other amputees around the world. The design has been and is continuing to be improved. The research and evaluation provided by VARR&D has stimulated extensive additional research into prosthetic feet and ankles both by the industry and by other worldwide prosthetic research sources.

Ankle/Shaft Unit. Activities related to development of additional lower limb prosthetic components continue to be based on energy storing and release incorporated in light composite materials design. Motion/force vectors are incorporated in the material itself with elimination of components ordinarily and traditionally used. A monolithic gravity-energy storing ankle/shank has been developed, bench and laboratory evaluated, clinically tested locally, and is now released for national field testing in 100 subjects. As with the Seattle Foot, the keel testing and evaluation will be a cooperative study between the VACO RR&D Section and Prosthetics and Sensory Aids Service.

The ankle provides controlled and programmed rotation, inversion-eversion and modestly enhances flexion/extension for the Seattle Foot when the two units are used together. This below-knee endoskeletal system will incorporate a new cosmetic foam cover being developed to complete the VA/Seattle System. National field testing should begin by the end of the year 1987.

Automated Fabrication of Mobility Aids (AFMA). Our facility is actively engaged in automated fabrication of below-knee prosthetic sockets through a working agreement with the University College, London, Roehampton Bioengineering Unit. Below-

knee residual limb shape sensing is accomplished by wrapping routine plaster casts for each subject. These casts are forwarded to our London collaborators to the milling and socket forming equipment where sockets are completed, using their rectification program. A "Trans-Atlantic" socket with a Seattle Ankle/Foot combination prosthesis is being worn by a Vietnam veteran. This computerized and automated fabrication system is providing us with sockets of essentially the same quality and fit as those obtained by conventional prosthetic techniques. Eleven below-knee amputees have been fitted to date and an additional ten subjects will be included by the end of 1987. Information derived from our research is being incorporated in the London database. Although no date has been set for commercial production, research is progressing rapidly at coordinating centers in this country.

We are continuing to investigate a variety of types of shape-sensing, including the incorporation of stiffness of the tissues as well as the physical shape. Automated fabrication systems are being studied both in this country, Canada, and a number of other centers throughout the world.

Limb Viability. Limb viability studies continue through recent extension of funding of the micro-wound biological structure investigation and TcPO₂ evaluation of the circulatory status of residual limbs under pressure. This latter information should be useful in the AFMA prosthetic project. A number of scientific publications accepted or awaiting merit review will describe the progress made in this essentially basic evaluation of the healing capacity of the skin *in vivo* in the presence of ischemia and related pathological states necessitating limb ablation.

The influence of platelet-derived wound healing

factor in the management of extremity wounds and ulcers, particularly in the diabetic, has been recently brought to our attention by Dr. David Knighton and his staff at the University of Minnesota. We are exploring the potential study of this exciting biological breakthrough as an outreach from the primary investigators.

Activities Related to This Research—The Prosthetics

Research Study (PRS) staff has participated in a regional workshop at VAMC, Minneapolis, MN, June 1987, a workshop at Portland VAMC September 1987, and a similar seminar at the University of New Mexico/VAMC Albuquerque, NM, also September 1987. A Western Regional IRMEC sponsored 3-day seminar for VA Physical and Occupational Therapists was held in Seattle in December 1986 where PRS staff provided faculty support.

CAD/CAM of Below-Knee Prostheses: Program Studies

Dudley S. Childress, Ph.D., and Yeongchi Wu, M.D.

Veterans Administration Medical Center, Chicago, IL 60611

Sponsor: VA Rehabilitation Research and Development Service (Project #XA317-2RA)

Purpose—The purpose of this project is to develop methods for the determination of interface pressure patterns, and then use those methods to evaluate many of the common strategies used to modify pressure patterns at the interface. Our particular method for determining interface pressure patterns uses finite element modeling of socket-limb mechanics. An advantage of the computer modeling methodology is that the many parameters which affect interface pressures can be systematically investigated without the need to build and instrument prostheses.

The finite element modeling process requires both geometric and material descriptions of the bones, soft tissue, and socket. The geometry information is obtained from a CT scan of an amputee's limb. The material properties of the bone and socket can be obtained from published literature or measured in a materials testing machine. The material properties of the soft tissue, however, are complex and not adequately documented. A reasonable material description must therefore be formulated for soft tissue. Verification of the finite element model is also important if meaningful results are to be obtained from this study. We will perform finite element analysis and *in vitro* testing of tissue samples in order to categorize the material properties of tissue such that pressure patterns predicted by the finite element model match those measured in the tests. This will formulate stage one of model development and verification.

Stage two of model development and verification involves finite element modeling and *in vivo* testing.

Finite element models of socket-limb mechanics for volunteer amputee subjects will be formulated. The socket interface pressure at various load states will be measured for each volunteer and a computer simulation performed. Predicted pressures will be compared with measured pressures and the model adjusted until the pressures correspond. At this point, an appropriate finite element description can be said to exist.

A generic finite element socket-limb model will be developed which uses a geometrically simplified representation of the residual limb. This simple model will then be used in a systematic analysis of prosthesis design parameters. Parameters will be varied one at a time and interface pressure patterns computed. The parameters to be investigated include: residual limb characterization (length and bulk), type of socket rectification, type of liner, and alignment state. This series of investigations is expected to increase our understanding of what factors govern interface pressure and may suggest new concepts which may be effective in the control of interface pressure.

Finally, we will develop devices and techniques that will allow us to rapidly and easily formulate finite element models for specific individuals. This will help us to expand our studies in the future. Additionally, such equipment and techniques may pave the way for integration of these methods into the clinical environment.

We intend to study the limb loading characteristics of 15 below-knee amputees in anatomically-based reference frames. The subjects will be required to

be considered "good" walkers. Their residual limbs will be of various lengths and tissue bulk, because these parameters are known to correlate with interface loading characteristics. The relations between amputee gait characteristics, limb loading, alignment, and skeletal anatomy will be studied using malalignments from known prosthetically acceptable alignment "set-points." Limb loading characteristics during walking, relative to skeletal anatomy, will be collected using techniques that have already been developed around the high accuracy, real-time display, and three dimensional information capabilities of the CODA-3 Movement Monitoring Instrument and the biomechanics platforms. From relations between alignment, loading, and skeletal

anatomy, we hope to define an "ideal" alignment set point that is specific to the amputee's skeletal anatomy. Thus, we hope to be able to make proper alignment decisions before amputees walk on the prostheses (*a priori* decisions).

Our ultimate goal is to develop a system to achieve successful alignment based upon anatomical factors in an attempt to replace the iterative process now used. The ideal is to be able to design and fabricate unitized prostheses automatically and quickly with non-adjustable alignment. By using CAD/CAM techniques, prostheses could be delivered in a short time and could be easily refabricated to make adjustments in either alignment or socket shape.

Computer-Aided Analysis of Below-Knee Prostheses Alignment

Dudley S. Childress, Ph.D.; Joshua S. Rovick, M.S.; Robert L. Van Vorhis, M.S.
Prosthetics Research Laboratory, Northwestern University, Chicago, IL 60611

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this on-going study is to establish a method of aligning below-knee prostheses which is quantitative, simple, and produces a more reliable alignment outcome. Malalignment of a prosthesis is manifested as an irregularity in the walking pattern for an amputee. Dynamic alignment is achieved by making adjustments to the foot position based on the particular walking irregularities observed. By using computers and sensitive transduction equipment, we hope to be able to quantitatively correlate the relationship between particular malalignments and their associated gait patterns.

Progress—We are in the process of assembling a gait analysis laboratory to be used in these studies. The CODA-3 Movement Monitoring Instrument is used for position transduction providing global X, Y, and Z-coordinates of up to eight passive markers. Two AMTI biomechanics platforms are used to get the six components of reaction force at the ground. A raised walkway is being constructed so that the walking surface is at the same level as the biomechanics platforms.

We have developed an approach methodology for the analysis of walking trials as they relate to prosthesis alignment and skeletal anatomy. Anatomically-based axis systems have been defined for each

of the body segments of interest; prosthetic foot, tibia, femur, and pelvis. Computer algorithms have been completed which determine the 3-D location of the hip joint centers by tracking the motion of a CODA landmark attached to the thigh. We have also designed a jig to find the primary flexion axis of the knee, and using a CODA-based, 3-D digitizing wand this axis is located in three-dimensional space. These joint location methodologies are used to provide precise and reproducible axis definition prior to testing.

The experimental protocol involves successive alignment perturbations from an ideal set-point and an analysis of the resulting gait deviations. An interactive computer-based nulling routine has been developed to aid in establishing the specific alignment states of both the "ideal" set-point and the perturbations from this set-point used during the walking trials.

Results—Assembly of the gait laboratory, and testing of the protocol are scheduled to be completed by the Fall of 1987. The first round of data collection took place in the Fall and Winter of 1987, with some preliminary from analysis of the data expected in the Spring of 1988.

Implications—The goal of our work is to investigate the feasibility that the foot of a below-knee prosthesis can be properly aligned without the need for dynamic walking trials. Such an alignment scheme would likely necessitate that a common anatomical basis be established in the limb of the amputee. Our experimental methodology is designed around this anatomical basis. The results of this investigation could then be transferred to the clinical setting by providing a means for locating a suitable anatomical reference. The immediate clinical usefulness of this

work would be the elimination of dynamic walking trials in the alignment process. Moreover, the introduction of automated methods into the clinic (i.e., CAD/CAM of prostheses) will make feasible fabrication of unitized prostheses which do not incorporate adjustable alignment components.

Publication Resulting from This Research

Anatomically-Based Gait Analysis for Below-Knee Prosthesis Alignment—An Experimental Method. Van Vorhis RL and Rovick JS, *ASME Bioengineering Division*, Boston, MA, December 1987.

Computer-Aided Analysis of Below-Knee Socket Pressure

Dudley S. Childress, Ph.D. and John W. Steege, M.S.M.E.

Prosthetics Research Laboratory, Northwestern University, Chicago, IL 60611

Sponsor: VA Rehabilitation Research and Development Service

Purpose—In this study, finite element (FE) models of the below-knee residual limb-socket system were analyzed in an attempt to predict interface pressures. The input parameters, which were experimentally measured, were socket geometry and the external load vector developed during stance. Beginning with simple but realistic assumptions, mechanical properties were assigned to the elements of the two models and simulations carried out. While FE analysis has come to be a widely used tool in many engineering fields, it has also come to be widely misused. Models that yield accepted results can be created which appear to represent the intended physical system but are in error when tested. An experimental pressure measurement methodology was therefore simultaneously developed to verify the results of our FE models. The pressure measurements made on two volunteers were compared to resultant pressures at the limb-socket interface as predicted by FE analysis.

Progress—In an effort to obtain static pressure measurements along the tissue/liner/socket interface, a methodology was devised. The resultant system proved to be linear and highly repeatable yet was dependent upon the type of semi-solid liner material. The transducer selected was a ruggedized, miniature KuliteTM pressure transducer (model XTM-190) with a maximum rated pressure of 0.35 MPa, a sensitivity of approximately 170 mV/MPa, and a piezoresistive strain gauge bridge circuit mounted

on a metal diaphragm used as a sensing element. The transducers weigh 8 grams and have a diameter of 4.0 mm and were easily mounted into the subjects' sockets at seven ports. Briefly, the placement of the transducers was at the medial tibial condyle, patellar tendon bar, distal end, popliteal area, distal lateral contact area, medial proximal tibia flare, and below the fibula.

We could not obtain consistent results when the transducer alone was mounted in the socket because it could not be made exactly flush with the inner surface. To ensure that the transducer's face would be flush with the socket, epoxy collars with a flat face one centimeter in diameter (larger than the diameter of the transducers) were machined to hold the transducers. The flat collar surface formed a small "area of measurement" on which the transducer could be mounted flush to the surface and locked into position. Although the addition of the collar would slightly alter the actual socket shape when the collar was threaded into the socket, the forcing of a flush fit of the transducer was felt to be of prime importance to ensure proper use of the gauge.

The 3-D geometry of the residual limbs of two volunteers was obtained from multiple transverse CAT scans (1 cm spacing). The CAT scan images were then digitized by hand on a tablet. Of the levels imaged for subject A, 13 were chosen for mesh development which represented critical geometric occurrences while 14 were chosen for subject B.

The mesh for subject A consisted of 1282 nodes defining 1017 linear 3-D isoparametric elements which represented the limb and 340 linear spring (boundary) elements which were added normal to the limb elements to represent the socket liner. The boundary elements act as linear springs resisting deformation and thus only require a spring stiffness. For subject B, the liner was represented with linear 3-D isoparametric elements as opposed to springs. Thus the mesh consisted of 1976 nodes comprising 1578 eight-noded elements. The first model was analyzed using SAP IVTM installed on a Cyber 845 while the second model was analyzed using a personal computer (PC) based code (GIFTSTM) which runs on an IBM AT.

The limb elements were assigned properties of bone, cartilage, soft tissue, or PeliteTM as appropriate. Bone and cartilage properties were obtained from the literature while that of PeliteTM was obtained experimentally. Pelite'sTM spring stiffness for subject A was found to be 145 N/cm while its Young's modulus (E) for subject B was 380 KPa. For the soft tissue, E was obtained by use of a plunger device which consisted of a small load cell and an LVDT and output load/displacement curves. For each subject, a socket was made with seven ports (corresponding to the points at which pressure was measured experimentally) to which the plunger device attached. During stance, the plunger was depressed into the tissue and load-displacement curves obtained. On the FE model, the ports were identified, corresponding socket liner elements removed, and unit normal compressive loads applied. The tissue was given an initial E value previously obtained at this laboratory (85 KPa) and analyzed. The values of E and displacement are proportional for these linear models. By comparing the ratio of FE analysis and experimental displacements at the ports to the initial E value, an average value of Young's modulus was obtained (60 KPa).

Along with geometry and material properties, the moments and loads developed during the stance of each subject must be applied to their model. This information was obtained by having the subjects stand on two force platforms (Advanced Mechanical Technology, Inc.) which measured XYZ forces, moments, and center of pressure. By observing oscilloscopes interfaced to the plates, subjects found and held comfortable positions with their weight evenly distributed. Position of the limb with respect

to the force platforms was measured simultaneously using a CODA-3 Scanner (Movement Techniques, Ltd.). Pressures at the port areas were measured concurrently using the KuliteTM transducers. Thirty samples of all parameters were obtained at 300 Hz every ten seconds for one minute. The resulting force and moments obtained for the sampled stance were transformed from the foot to the proximal femur in the FE model by satisfying equilibrium conditions.

Preliminary Results—The FE analyses were performed and resulting predicted pressures for subject A (a distal end weight bearer) ranged from 0 to 9 N/cm² (0.6 at the popliteal artery; 9 at the patellar tendon bar [PTB]) while the experimentally measured pressures ranged from 0 to 11 N/cm² (zero at the popliteal artery; 5 at the PTB). The predicted pressure at the distal end was 5 N/cm² while the measured pressure was 11 N/cm².

Pressures predicted for subject B ranged from 0 to 30 N/cm². It should be noted that contour plotting for subject B through GIFTSTM which allowed for identification of small local concentrations of pressure (up to 30 N/cm²) such as was predicted beneath the PTB. If the element corresponding to the location of the PTB pressure gauge was located on the model it was found that across the element face, there was a predicted pressure range of 2 to 12 N/cm². Thus the measured pressure could be expected to fall within this range and in fact was measured to be 8 N/cm². Predicted pressures around the remainder of the limb were 0 to 3 N/cm² except for the popliteal area where the predicted pressure was 6 N/cm². Measured pressures around the remainder of the limb were 0 to 6 N/cm² except for the popliteal area which was 8 N/cm². Finally, the predicted and measured pressure at the distal end was zero, and this corresponded well with the fact that the subject was a non-distal end weight bearer.

Future Plans—It can qualitatively be seen from the first two subjects analyzed that the FE technique possesses the capability to predict pressure ranges developed between the limb and socket with reasonable accuracy. From the results of subject B it is demonstrated that there may exist local hot spots of pressure around which high pressure gradients exist. This points out the need in future analyses to locate the small measurement face of the transducers

accurately with respect to the model and also to increase the density of elements in areas which are expected to develop relatively high pressures (i.e., PTB, popliteal area, distal end). This mismatching of model and transducer may be one reason why a one to one correspondence between predicted and measured pressures was not demonstrated. This lack of correspondence could be due to several other factors. Initially, we have examined amputees wearing well-fitted sockets. These sockets were made from rectified molds and may not provide the contact continuity assumed in the model between limb and socket. Additionally, the soft tissue may better be represented by nonlinear elements. In the future,

we will test subjects fitted with unrectified sockets to assure initial contact of the entire limb with the socket. Also, we are converting to a nonlinear mainframe code (MARC™) in order to investigate nonlinear effects of materials on the model.

Publications Resulting from This Research

Finite Element Analysis as a Method of Pressure Prediction in the Below-Knee Socket. Steege JW, Schnur DS, Van Vorhis RL, Rovick J, *Proceedings 10th Annual RESNA Conference*, 7:814-816, June 1987.

Prediction of Pressure at the Below-Knee Socket Interface by Finite Element Analysis. Steege JW, Schnur DS, Childress DS, *Symposium on the Biomechanics of Normal and Prosthetic Gait*, Boston, MA, December 1987.

Development of the ISNY Below-Knee Flexible Socket System

S. Fishman, Ph.D.; N. Berger, M.S.; D.E. Krebs, Ph.D.

New York University Post-Graduate Medical School, New York, NY 10016 and Veterans Administration Medical Center, New York, NY 10010

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The goal of this project is to adapt the successful Icelandic-Swedish-New York University (ISNY) Above-Knee Flexible Socket to below-knee (BK) amputees.

Progress—The central design concept relates to the provision of the two fundamental prosthetic socket functions, “weight transmission” and “hydrostatic containment,” utilizing two separate structures (a flexible socket contained within a rigid frame), rather than by the conventional single, rigid, laminated structure.

Socket. The most important characteristics of the tissue-containing socket are transparency, thinness and flexibility (consistent with requisite strength and durability), and an extremely intimate fit of the residual limb. This “sheath” fit requires great care and precision in casting and cast modification procedures, as well as the mandatory use of “check” sockets. Our studies indicate that the preferred socket material is sheet low-density polyethylene (1/4 to 3/16 inch Ethylux) which is heated and drawn over the modified plaster residuum model to produce socket wall thicknesses of 0.030 to 0.060 inches.

Frame. The design employs a three-strut “inverted tripod” configuration, consisting of a proximal horizontal brim connected to a distal end cup by two anterior struts and one posterior strut (1/2

inch to 3/4 inch wide and 1/6 inch to 1/4 inch thick). The proximal brim originates at the anterolateral strut, runs medially to support the patellar tendon, continues around the medial side to support the tibial flare, and terminates posteriorly at the lateral edge of the popliteal fossa.

The anteromedial strut supports the tibial shaft, running 1/4 inch medial to the tibial crest; the anterolateral strut supports the soft tissue (primarily dorsiflexor remnants) just lateral to the tibial crest; and the posterior strut prevents frame deformation by supporting the popliteal segment, running vertically downward from its center.

There is an interface of 1/5 inch thick Pe-lite padding between the frame and the socket to diffuse any edge pressures and provide a more comfortable force distribution. Eight layers of 1/4 inch width carbon-fiber filament tape, nylon, Dacron and Xynole material laminated into a composite with polyester resin is required for a sufficiently rigid and durable frame.

Suspension. Separate designs have been developed to accommodate the three major types of below-knee suspension. The conventional cuff is placed in the usual location—attached to the rigid frame medially and to the polyethylene socket laterally. In the supracondylar suspension the areas below the proximal frame extensions are left open and the

usual wedges are utilized. In the corset design, the proximal frame surrounds the entire residuum to: a) provide an attachment point for the lateral upright; and b) to enhance structural stability.

Preliminary Results—All told, 28 patients participated in the project—13 in the developmental aspects and 15 in the clinical evaluation of the final designs. Eleven of these latter patients continue to wear the ISNY sockets full-time. Patient reactions have been very positive, citing the more intimate and natural fit, greater freedom for muscle activity, improved suspension and prosthesis control, lighter

weight, coolness, fewer skin breakdowns, and generally increased comfort.

Implications—For the prosthetist, the considerable transparency and the economies afforded in the socket modification and/or replacement are significant features.

Publication Resulting from This Research

Fabrication Procedures for the ISNY B/K and A/K Flexible Socket Systems. Fishman S, Berger N, Krebs DE, Faculty, *Prosthetics and Orthotics*, New York University Post-Graduate Medical School, 42 pp., June 1987.

Patterns of Perfusion as Assessed by Quantitative Perfusion Fluorometry That Could Affect the Outcome of a Below-Knee Amputation

Gordon R. Neufeld, M.D.; Andrew B. Roberts, M.D.; Cheryl A. Reilly, B.S.N.; David G. Silverman, M.D.
Division of Vascular Surgery, Medical College of Pennsylvania; Department of Anesthesia, University of Pennsylvania School of Medicine; Department of Anesthesia, Yale University School of Medicine; Division of Anesthesia Research, Veterans Administration Medical Center, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project was to determine if there is a decrease in blood flow medially, laterally or posteriorly at the site of incision that affects the healing of below-knee amputations (BKA).

Progress—The perfusion patterns of 77 legs assessed pre-operatively for either an above or below knee amputation were compared retrospectively with those of 105 control legs of patients with peripheral vascular disease (PVD). Three 1-cm sites were analyzed (3 cm medially to the tibial, 3 cm laterally to same, and posteriorly on the calf) at three levels (10 cm and 2 cm below the knee and 5 cm above the knee) to determine if there was a gradient. It was evident from the data that there is a decrease in perfusion laterally below the knee, in ischemic limbs, that could affect the outcome of a standard below-the-knee amputation, which utilizes a long posterior flap.

Results—The DFI (dye fluorescence index) of the 14 failed BKA's laterally was 41 ± 30 (which is

within the borderline zone of healing of 38 ± 42) while the DFI of the 45 healed BKA's laterally was found to be 56 ± 20 . The 105 control legs showed a different perfusion pattern, with DFI's well above the cutoff. Our findings are consistent with McCollum (McCollum PT, Spence VA, Walker WF: "Circumferential Skin Blood Flow In the Ischaemic Limb," *Br J Surg*, 72:310-312, 1985), and suggest that preoperative assessment with quantitative perfusion fluorometry (QPF) can determine a lateral gradient significant to the healing or failing of a below-knee amputation.

Future Plans—A study is being planned to prospectively evaluate patterns of perfusion in all amputations and how this affects healing.

We are comparing preoperative angiograms of vascular surgery patients to QPF studies obtained preoperatively to see how skin perfusion is affected, and we are presently comparing medial and lateral aspects of perfusion, using the Laser Doppler and QPF.

Diabetic Foot Ulcers—Quantifying the Effects of Nonsurgical Treatments

Roger Pecoraro, M.D.

Veterans Administration Medical Center, Seattle, WA 98108

Sponsor: VA Rehabilitation Research and Development Service (Project #XA318-2RA)

Purpose—Most amputations due to foot ulceration in diabetes result directly from either infection or failure of wound healing. Since chronic hyperglycemia has been implicated in many of the mechanisms responsible for wound failure, we hypothesize that efficient wound repair is impeded in diabetic patients with suboptimal control of diabetes, increasing their risk for amputation. We wish to test whether precise medical management of diabetes, nutritional supplementation with ascorbic acid and zinc, or application of total contact casts, combined with appropriate surgical and local wound care practices, will substantially improve the rate of ulcer healing.

We propose to recruit and characterize a population of diabetic patients with foot and lower extremity ulcers, in order to evaluate prospectively the status of healing of their cutaneous ulcers. Patients who present or are referred with similar ulcers, based on a standardized wound classification system, will be randomized to groups receiving specified treatment interventions in addition to standard care. Wound healing will be measured objectively by blinded sequential computerized calculations of ulcer area based on direct wound tracings and standardized photographs. The proposed study will be conducted over three years and involve 150 subjects. Specific objectives are:

1) Develop an objective method to quantitate the healing progress of cutaneous ulcers.

2) Compare the rates of ulcer healing among patients randomized according to a 2x2x2 factorial ANOVA design. The factors are: (I) intensive diabetes management for optimal control of diabetes;

(N) nutritional supplementation with zinc and ascorbic acid; and, (W) ulcer severity (note that this is a stratification). The control therapy group will receive conventional medical and surgical management.

3) Compare the rate of ulcer healing among an additional smaller subset of patients with plantar foot ulcers which fall within a single defined stratum of ulcer severity and meet specified criteria for treatment with total contact casts. Patients will be randomized according to a 2x2x2 factorial ANOVA, with factors including I (see above); N (above); and (C) sequential applications of total contact casts.

4) Survey the biomedical characteristics of all subjects, including the status of diabetic control, vascular integrity, extent of neuropathy, and characteristics of the cutaneous ulcer. These factors, combined with the measured initial rate of ulcer healing, will be analyzed retrospectively to define characteristics of the patient and the foot lesion which predict the probabilities of ulcer healing, chronic wound failure, or other definitive medical outcomes.

5) Examine the independent effects of the experimental treatment interventions on the eventual distribution of definitive outcomes of foot ulceration.

6) Examine the potential utility of a novel adaptation of NMR spectroscopy to measure noninvasively the metabolic status of ulceration cutaneous tissue. We will test whether cutaneous ATP and NADPH levels will improve during effective treatment, in particular with precise medical management of diabetes, and whether changes will correlate with healing progress.

Finite Element Analysis of a Below-Knee Prosthesis

Harry B. Skinner, M.D., Ph.D., and Peter M. Quesada

Veterans Administration Medical Center, San Francisco, CA 94121

Sponsor: American Federation for Aging Research

Purpose—In the USA a majority of the 80,000 amputations performed per year are below-knee

(BK) amputations. Many BK amputees complain that prostheses are heavy and uncomfortable, and

a portion are subsequently confined to wheelchair existences.

Numerous investigators have studied and reported on the subnormal gait characteristics of BK amputees using prostheses. Other investigators have reported on the problems associated with the prosthesis/stump interface.

This study utilizes the finite element method to determine the stresses and displacements at the prosthesis/stump interface. This information is then used in prosthesis design in order to minimize displacements and stresses at the interface, and thus provide reduced pain and greater comfort.

Progress—This 3-D finite element study is being conducted with a base model consisting of 636 nodes and 655 quadrilateral and triangular constant strain shell elements. Base model node coordinates were measured directly from a right exoskeletal BK prosthesis and socket. Elements in the base model were taken to be 0.5 cm thick. The nodes of the socket were then supported by springs to model the soft tissue of the stump. The material properties of the base model were those of a composite of polyester resin and fiberglass. A resultant load of 984 N was

equally distributed among three nodes at the heel at an angle of 9 degrees from the positive Z-axis, 81 degrees from the negative X-axis, and 88 degrees from the positive Y-axis, in order to simulate the direction of the forces at heel strike. The analysis was performed on an IBM PC/AT using the finite element program, SAP80; and plots were generated by the accompanying program, SAPLOT.

Preliminary Results—The finite element analysis was performed for the base model. The resulting forces at the interface are being used to calculate the interface pressures. These pressures will then be compared with other investigators' experimentally measured pressures in order to verify the results of the analysis. Several altered models have been prepared with the intention of reducing the interface pressures.

Future Plans—The models will be analyzed following verification of the results of the base model. The pressures obtained for each altered model will then be compared with those of the base model in order to determine if the changes made for each altered model succeeded in reducing the interface pressures.

Design and Construction of a Bicycle Attachment for Conditioning of Below-Knee Amputees in the Early Postoperative Stage

A. Esquenazi, M.D.; T. Vachranukunkiet, M.D.; W. Micheo, M.D.

Gait and Motion Analysis Laboratory, Moss Rehabilitation Hospital, Philadelphia, PA 19141

Sponsor: Moss Rehabilitation Hospital Research Fund

Purpose—We have identified the need for a device that would permit below-knee amputees to exercise large muscle groups of both lower extremities without interfering with early wound healing. The use of upper extremity and one-legged exercises has been attempted, to improve conditioning in the amputee, with limited results. Upper extremity exercises use muscle groups which fatigue easily and increase blood pressure. Also, there has been proven to be no transferability of training from upper extremity exercise to lower extremity exercise, particularly ambulation. One-legged exercises, on the other hand, are difficult to perform by the patient and would not provide training of the amputated limb. Ambulation to improve cardiopulmonary endurance is well known. Unfortunately, for this

population, in the early postamputation period, the condition of the residual limb will generally prevent ambulation even with an immediate postoperative pylon.

Progress—We have designed and constructed a device that permits the attachment of the below-knee residual limb to a stationary bicycle: thus, bilateral lower extremity exercises to attain early cardiovascular and musculoskeletal conditioning are possible, which we believe will facilitate the patient's prosthetic rehabilitation and may aid in stump maturation.

The device consists of a vacuum form polypropylene socket with an inflatable polyethylene open-ended insert, and a length-adjustable metal shank

inserted into a quick-disconnect unit, which in turn is attached to the bicycle pedal. The system is fully adjustable in length, diameter, amount of pressure applied to the residual limb, and is interchangeable for right and left.

Preliminary Results—Testing of the device on four patients revealed good adjustability, patient tolerance and acceptance to the device. There was no evidence of skin irritation or reports of pain in any of the subjects. The subjects were able to pedal up to 15 minutes without residual limb complications or excessive muscle fatigue. Evidence of cardiac

and respiratory response necessary for conditioning were present.

Future Plans/Implications—Two prototypes have been fabricated, and a follow-up clinical trial study to assess cardiovascular and musculoskeletal effects will be undertaken. Future applications of this device are in the cardiovascular exercise testing of below-knee amputees.

The device at this time has a patent pending and the initial results of the project have been presented at the Fifth World Congress of the International Society for Prosthetics and Orthotics.

Investigation of the Optimal Load Bearing Characteristics of Patellar Tendon Bearing (PTB) Prostheses

R. Seliktar, Ph.D.; T. Vachranukunkiet, M.D.

Department of Mechanical Engineering, Drexel University, Philadelphia, PA 19104 and Moss Rehabilitation Hospital

Sponsor: *The National Science Foundation*

Purpose—The specific aim of this project is to broaden the knowledge pertaining to transmission of loads through the stump-prosthesis interface. Understanding the mechanisms of the load bearing will pave the way toward analytical synthesis of prosthetic sockets. Such synthesis is necessary in order to proceed toward automated Computer Integrated Manufacturing of lower limb prostheses.

The long-term goals of our research efforts are to supplement this study by two additional investigations aimed at: 1) synthesis of an optimal structure of a whole prosthesis from the dynamic point of view; and 2) studying the amputee's compensatory activity resulting from psychological attitudes.

Based upon the accumulated knowledge from all three studies, a scheme for construction of customized prostheses will be developed. This scheme will ultimately be translated into design and manufacturing algorithms to facilitate objective and optimal delivery of prostheses to the amputees. This will lead to a substantial improvement in the quality of prosthetic care delivery, which, at present, is heavily dependent on the artisan skills of the prosthetic team.

Progress—The aims of the original proposal were focused on the understanding of the patellar tendon bearing concept. These were later broadened to

cover other bearing areas, such as the stump end and the tibial flares. At the present stage, further expansion of the project and its supplementation by mathematical modeling is being considered.

Preliminary Results—The following is a summary of the accomplishments and the results obtained during the first eighteen months of the work.

1) Altogether, nine patients were involved in this study, two of whom withdrew in the middle of the experimentation. Information is therefore available on seven subjects and more are currently being fitted with prostheses.

2) The original patellar-tendon transducer was modified and implemented in the more recent prostheses. The stump-end-bearing transducer was designed and had undergone several changes since its original implementation. Several designs for implementation of load cells to monitor forces on the tibial flares were considered and rejected due to technical limitations. The idea of expanding the scope of the study in this direction was abandoned. However, this information will be obtained through mathematical modeling of the socket.

3) A preliminary stage of mechanically modeling the stump for the purpose of improving its determinacy is currently in progress.

4) Preliminary results of the dynamic model of

the man-prosthesis were obtained and reported in the meeting of the International Society for Prosthetics and Orthotics.

5) Some experimental results have been analyzed and reported in the relevant literature.

6) In the first stages of the analysis, some very interesting discoveries were made regarding limitations of weightbearing, and interplay between the different load-bearing zones of the socket. These were partially reported in relevant publications and some findings are still in the process of preparation for presentations.

Publications Resulting from This Research

Gait Performance and Dynamic Characteristics of Weightbearing on the Patellar Tendon in PTB Prostheses. Mizrahi J, Seliktar R, Bahar A, Susak Z, Najenson T, *Biomechanics IX-A*:581-586. D.A. Winter (Ed.), Human Kinetics Publishers, 1985.

Biomechanical Evaluation of an Adjustable Patellar Tendon Bearing Prosthesis. Mizrahi J, Susak Z, Bahar A, Seliktar

R, Najenson T, *Scandinavian J. Rehab. Med. Suppl.* 12:117-123, 1985.

Optimization of Stump Load Bearing with B.K. Prostheses. Seliktar R, Besser J, Vachranukunkiet T, Mizrahi J, *Proceedings of the 38th ACEMB* 38, 1985.

Gait Characteristics of Below-Knee Amputees and Their Reflection in the Ground Reaction Forces. Seliktar R, Mizrahi J, *Engineering in Medicine*, 15(1):27-34, United Kingdom, 1986.

Dynamic Modeling of Human Motion and its Relevance to Lower Limb Prostheses. Seliktar R, *Proceedings of the 5th World Congress of the International Society for Prosthetics and Orthotics*, Copenhagen, June 1986.

Optimization of Residual Limb-Socket Load Bearing of Below-Knee Prostheses. Vachranukunkiet T, Seliktar R, Besser M, Demopoulos JT, *Proceedings of the 5th World Congress of the International Society for Prosthetics and Orthotics*, Copenhagen, June 1986.

Structural Synthesis of Lower Limb Prostheses for Optimal Gait Performance. Seliktar R, *Proceedings of the 13th Northeast Bioengineering Conference*, Philadelphia, PA, March 1987.

Toward Automation of the Manufacturing of Lower Limb Prostheses. Seliktar R, *Proceedings of the Special Congress of the International Society for Prosthetics and Orthotics*, Israel, September 1987.

Functional Comparison of Single-Axis and Solid Ankle Cushion Heel Prosthetic Feet in the Dysvascular Below-Knee Amputee

Sanford H. Anzel, M.D.; Thay Q. Lee, M.S.; Robert Baird, M.D.; Leslie Torburn, M.S., P.T.; Jacquelin Perry, M.D.; Edmond Ayyappa, C.P.O.; Bruce Thoma, M.D.; Mike Coen, B.S.
Rancho Los Amigos Medical Center, Pathokinesiology Department, Downey, CA 90242 and Veterans Administration Medical Center, STAMP (117S), Long Beach, CA 90822

Sponsor: *Special Team for Amputations, Mobility, Prosthetics/Orthotics (STAMP)*

Purpose—This comparative gait lab study looks at the effects on gait to the dysvascular below-knee patient population wearing both single-axis and SACH prosthetic feet. It also investigates the effect of changing plantar flexion bumper compression in the case of single-axis feet and the effect of changing the durometer of heel cushion density in the case of SACH.

Progress—Twelve below-knee dysvascular amputees were fitted with a succession of 6 prosthetic feet and underwent gait lab analysis. The feet tested were comprised of 3 SACH designs (with firm, medium, and soft heel densities) and 3 single-axis designs (using 3 different levels of bumper compres-

sion). Subjects selected for the study were experienced amputees who walk without upper extremity aids on a community ambulatory level and who have been screened for consistent walking patterns. Initial screening was done using the footswitch stride analyzer. Definitive gait testing included dynamic EMG, footswitch stride analysis, dynamic knee goniometer measurements, and ground reaction force analysis with a force plate. The correlation between type of foot with velocity and other gait characteristics, time of EMG firing, and joint torques was determined comparing each subject to himself. Data was examined for relevant differences and evidence of gait advantages in each of the feet.

B. Lower Limb

3. Above-Knee

Gait and Energy Expenditure in Above-Knee Amputees: Differences Between Socket Types

Mark I. Bresler and Stephanie D. Burns, R.P.T.

Veterans Administration Medical Center, Oklahoma City, OK 73104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The original intent of the study was to find differences in prosthetic sockets for above-knee amputees. Energy expenditure and gait characteristics were to be studied to determine if Contoured Adducted Trochanteric Controlled Alignment Method (CAT-CAM) sockets significantly differ from Quadrilateral sockets in the monitored characteristics. The study is being modified to describe the gait characteristics of above knee CAT-CAM wearers.

Progress/Methodology—Originally, this study intended to have 12 male above-knee amputee subjects. At the start, each subject would be using a prosthesis with a quadrilateral socket. The subject's gait would be recorded with a Vicon Motion Analysis System, and energy expenditure would be monitored with a CAD/NET 2001 by analyzing expired air. Next, the subject would change his prosthetic leg to one with a CAT-CAM socket and the measurements would be retaken. By analysis of the differences between sockets for the same subject, it was hoped to determine if socket type indeed made a difference in gait or energy expenditure. However, several equipment problems greatly delayed accurate setup and use of the Vicon system as well as the CAD/NET 2001. Second, the number of potential subjects, i.e., those with a quadrilateral socket prosthesis in good repair and recently fitted with a CAT-CAM socket prosthesis having similar components was smaller than initially thought. Third, the cost figures provided by the prosthetist proved

to be greatly underestimated. This resulted in insufficient funds to insure that the prosthetic components for each limb were similar except for the socket. We were then unable to control enough variables to allow comparison only between the socket types.

Preliminary Results—Three subjects have been monitored at the laboratory, with one subject's data deemed unuseable. Of the remaining two subjects, energy expenditure was less using the CAT-CAM socket, but gait analysis was inconclusive. Our experience so far has led us to conclude that a descriptive study of gait characteristics of CAT-CAM wearers will form the basis for future comparative studies of Quadrilateral versus CAT-CAM sockets.

Future Plans—Recently some major technical problems in the motion analysis laboratory have been corrected and recruitment of subjects will resume shortly. In view of the difficulty in finding proper subjects, a redirection of the study is being considered. This revision would entail a descriptive report on the gait characteristics of twelve CAT-CAM socket users. If equipment and personnel allow, energy expenditure data will also be collected.

Preliminary results of this work were published in the *Proceedings of the Tenth Annual Conference on Rehabilitation Engineering*, RESNA, San Jose, CA, June 1987.

Geriatric Prosthetics: Design and Development of an Improved Above-Knee Socket

Hans R. Lehneis, Ph.D., C.P.O.; Gustav Rubin, M.D.; Vern L. Houston, Ph.D., C.P.O.;
Mary Anne Garbarini, M.A., P.T.

New York University Medical Center/Rusk Institute of Rehabilitation Medicine, New York, NY 10016 and
Veterans Administration Medical Center, New York, NY 10010

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The forces and moments transferred to and from an amputee's stump and his/her prosthesis are frequently uncomfortable and often painful. The way these forces and moments are distributed over an amputee's stump is determined by the design of the prosthetic socket, its fit, and alignment.

The stump musculature, biomechanical tissue characteristics, and circulatory and general physiological properties differ markedly between young, vigorous amputees and geriatric amputees. The ability of the soft stump tissues of these two types of amputees to support loading varies considerably, but for all above-knee (AK) amputees, sockets of the same design, and alignment and fit with respect to the same criteria, are currently used.

The purpose of this project is to investigate and determine the prosthetics needs of geriatric AK amputees, and to develop quantitative socket design criteria and procedures for deriving socket designs affording optimum or near-optimum fit, comfort, and performance for geriatric AK amputees.

Progress—Work has continued on measuring and compiling a computer database of physiological, biomechanical, and prosthetics parameters on geriatric and non-geriatric AK amputees and control subjects. Forty-eight subjects have been tested to date. From these subjects a number of significant statistical trends have been observed.

All geriatric subjects, amputees and non-amputees alike, have evidenced circulatory impairment to some degree. No common, localized regions of poor or good circulation have been observed on the stumps of the geriatric AK amputees tested, however.

Tissue mechanical elasticity has been shown to be anisotropic for all of the subjects tested. Tissue elasticity has been lower (less elastic) on the stumps of the AK amputees tested. Geriatric amputees, in general, have evidenced lower tissue elasticities than nongeriatric amputees. As with circulation, there have been no common, localized regions or direc-

tions exhibiting higher or lower elasticity on the stumps of the subjects tested. Although some sensory diminution has been noted in four geriatric AK amputees, no major sensory or proprioceptive impairment has been observed in any of the subjects tested to date.

Work has continued on AK socket design in conjunction with the physiological and biomechanical testing. Investigations using tissue compliance measurements with uniform cross-sectional loads for quantitative derivation of socket shape, as previously described, have continued. Results to date indicate that it may be possible to evaluate stump tissue compliance, and hence socket shape, at eight or nine key locations per cross-sectional level, rather than the 28 to 32 locations previously tested. Compilation of data on prosthetic loading, load distribution, and load tolerance ranges as a function of stump tissue compliance has continued.

Sockets for four more subjects were fabricated and incorporated in prostheses for clinical evaluation and testing, using the uniform force/tissue displacement socket design method developed under the project and described in previous progress reports. The sockets fitted to date have all been judged comfortable and stable antero-posteriorly, medio-laterally, and rotationally. It has been observed that the load tolerance ranges (i.e., the range of cross-sectional pressures needed for support and ambulation that are still deemed comfortable by a patient) are noticeably smaller for patients subject to significant stump volume variations. In total-surface-bearing sockets, this can place a rather severe constraint upon the socket fit required. This dramatically underscores the need for developing quantitative socket design and fitting procedures that would enable expeditious derivation of the optimum socket design.

Future Plans—Current physiological, biomechanical, and prosthetics parameter measurement and socket design studies will continue. In addition,

investigation of the effects of prosthetic socket loading upon stump circulation will begin. Stump/socket normal and shear-stress loading studies using instrumented sockets will also be conducted. The present project work on determining prosthetic load-

ing, load distribution, and load tolerance ranges as a function of stump tissue compliance will be expanded to include stump tissue viscoelasticity studies for derivation of optimum stump/socket load distribution, and hence, optimum socket shape.

Myoelectrically Controlled Above-Knee Prosthesis

Gordon D. Moskowitz, Ph.D.; Ronald J. Triolo, Ph.D.; Howard Hillstrom, M.S.

Drexel University, Philadelphia, PA 19104 and Veterans Administration Medical Center, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service; Gait Laboratory, Moss Rehabilitation Hospital, Philadelphia, PA

Purpose—The need exists for active volitionally-controlled above-knee (A/K) prostheses which are more easily controlled by the amputee. Currently, control of lower limb prostheses has been largely limited to preprogrammed, passive devices which are awkward and difficult to control, the most popular means of passive control being the use of fluid damping mechanisms at the knee joint. Active volitional control of a prosthesis permits continuous adjustments to changing gait conditions, decreasing metabolic energy usage, and the ability to respond to extraordinary events, such as stumbling.

A myoelectrically controlled A/K prosthesis is under development at this laboratory that provides greater conscious and subconscious active control in gait and nongait activities. This prototype prosthesis has three principal operating subsystems: a myoelectric signal processor, a controller and a hydraulic/pneumatic (H/P) actuator. The myoelectric signal processing that we employ includes spatial pattern recognition and time-series methods.

Progress—Progress has been made in the following areas:

a) Successful application of spatial pattern recognition methods in discrimination between intended knee and hip activity among normal and above-knee amputee subjects.

b) Development of a pneumatically powered A/K test actuator with the following characteristics: 1) the ability to produce torques actively and in opposition to externally applied torques; 2) the ability to recover energy as opposed to conventional actuators which act only as energy dissipators.

c) Successful integration of the actively powered test actuator with the spatial pattern recognition control algorithm.

d) Demonstration of an alternative control strategy based on time series features of the EMG signal.

e) Development and verification of a complete and robust multichannel time series myoprocessor which performs both limb function classification and muscle force estimation. The system consists of an optimal myoprocessor applied to the prewhitened residual sequences of each AR filter employed in the limb function classifier and offers the following advantages: 1) Modelling the EMG as an autoregressive process incorporates temporal information which reduces the number of electrodes required for the reliable detection of the direction of intended limb motion; 2) Incorporating spatially distributed information in the parallel filtering classifier by modeling multiple channels of EMG activity as a vector process with multidimensional AR filters increases the peak performance of the detection system, reduces classifier sensitivity to exertion level, and expands the operating range to include clinically useful levels of contraction; 3) Prewhitening the EMG with AR filters extends and completes the optimal myoprocessor to include multiple channels of serially correlated data. It allows both muscle force estimation and limb function detection to be accomplished simultaneously by a single, hybrid system with great computational economy. The multichannel time series myoprocessor (MTSM) represents the first time series based system to provide both binary decisions and a proportional control signal, and therefore specifies a complete and self-consistent intent recognition system.

f) Development of Gaussian Bayesian reference models for EMG based intent recognition and real-time control of artificial lower limb was accomplished. SNR and percent CC were obtained and proved superior to short term models. Minute and

hour scale stationarity was observed in parameters that were nonstationary in short time models.

g) Simulation, design, and fabrication of a second generation actuator prototype has been completed. This new actuator is a hybrid hydraulic/pneumatic which is currently being assembled.

Results—EMG patterns were collected for 10, 20, and 40 percent MVC moment levels about the medial-lateral axis of the knee over a 4-hour time span. These data were obtained via a controlled paradigm where target profiles containing knee moment ramps and plateaus were visually tracked. Gaussian Bayesian reference models have been extended to include ensemble averages of five and eight of these data sets. At present, an eighth order reference model has demonstrated the most robust performance of the spatial pattern recognition based intent recognizers.

The hybrid multichannel time series myoprocessor (MTSM) system, which consists of parallel filtering limb function classifier and optimal myoprocessor subsystems, has been implemented off line and evaluated extensively with EMG data from isometric, constant force contractions. System performance in terms of percent correct classification of limb function and fidelity of estimates of muscle force were compiled and found to be in agreement with expected results and previously reported results of system simulations. Significant increases in operating range of the intent recognition system were observed when additional channels of EMG data were added to the processor. The gains in SNR of the estimated joint moments were less than those predicted by the simulations and reported for application of the optimal myoprocessor subsystem on the raw EMG of isolated muscle without the prewhitening transformation of the MTSM. This behavior was attributed to the fact that recording channels were located between muscles to maximize classifier performance from a minimal set of electrodes. Two criteria for optimal electrode location based on classifier performance for the time series system were tested. Results were inconclusive and neither criteria was able to predict the location of the best single channel system. It was also impossible to predict multichannel classifier performance from single channel results. The effects of channel location on joint moment estimation are being investigated in an effort to improve the fidelity of the

estimates without sacrificing classifier accuracy or robustness.

The new actuator prototype has been assembled, and its control programs completed. The unit is currently being bench tested. The prototype was completed as planned.

Future Plans—Plans have been formulated to study the requirements of implementing the (MTSM) myoprocessor in real-time and to interface it to the A/K joint actuator. The effects of sampling rate, computational window size, and special AR model structures on system performance are being addressed in order to minimize the mathematical operations required to make a decision and to set the hardware and software requirements of a real-time system.

The completed laboratory prototype will be gait lab tested. Conversion of the unit to a free ranging preclinical form is planned. This untethered prosthesis will then be ready for more realistic testing outside of the gait laboratory.

Publications Resulting from This Research

Comments on Upper Extremity Limb Function Discrimination using EMG Signal Analysis and The Relationship Between Parallel - Filtering and Hypothesis Testing Limb Function Classifiers. *IEEE Transactions on Biomedical Engineering*, BME-52(3), March 1985.

The Effects of Myoelectric Signal Processing on the Relationship Between Muscle Force and Processed EMG. *American Journal of Physical Medicine*, 64, (3), 1985.

Biomedical Evaluation of Myoelectric Above-Knee Prosthesis. *Proceedings of the 38th Annual Conference in Medicine and Biology*, Vol. 27, 1985.

Simultaneous Limb Function Identification and Force Estimation. *Proceedings of the 38th Annual Conference in Medicine and Biology*, Vol. 27, 1985.

EMG Characterization for Real Time Control. *Proceedings of the Frontiers of Engineering and Computing in Health Care, 7th Annual Conference of IEEE/Engineering in Medicine and Biology Society*, 1985. (Also Abstract-*IEEE Transactions on Biomedical Engineering*, BME-32(10), October 1985.

A Multichannel Time Series Myoprocessor for Robust Classification of Limb Function and Estimation of Muscle Force. *Proceedings of the Frontiers of Engineering and Computing in Health Care, 7th Annual Conference of IEEE/Engineering Transactions on Biomedical Engineering*, BME-32 (10), October 1985.

Experimental Demonstration of a Time Series Myoprocessor for the Control of an A/K Prosthesis. *Proceedings of the 8th Annual IEEE EMGS Conference*, Dallas-Fort Worth, TX, November 1986.

Channel Selection for Multichannel Time Series Myoprocessor. *Proceedings of the 39th Annual Conference on Medicine and Biology*, Vol. 28, Baltimore, MD, September 1986.

A 2D Force Feedback Monitor for Repeatable Muscle Contractions. *Proceedings of the 39th Annual Conference in Medicine and Biology*, Vol. 28, Baltimore, MD, September 1986.

Spatial Pattern Recognition Reference Model Building. *Proceedings of the 8th Annual Conference, IEEE Frontiers in Health Care*, Fort Worth, TX, November 1986.

Optimization of Amputee Prosthesis Weight and Weight Distribution

H.B. Skinner, M.D., Ph.D.; C.D. Mote, Ph.D.; Sidney Sun; Elwood F. Agasid
Veterans Administration Medical Center, San Francisco, CA 94121

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Past patient surveys, conducted by Rehabilitation R & D at the VAMC in San Francisco, indicated a desire by many patients for a “light weight” prosthesis. However, it is argued by some researchers that too little weight in a prosthesis will hinder maintenance of forward velocity. The purpose of this project is to determine optimal weight and optimal weight distribution characteristics of AK amputee prostheses.

Progress—Determination of optimal prosthesis weight and weight distribution will be accomplished via examination of the mechanical energy required to move the prosthesis and by measuring the amount of energy or oxygen consumed in moving the limb. Work energy principles will be applied in the analysis of amputee gait to determine mechanical energy requirements. Hot wire anemometry will be utilized to measure translational velocity. The Douglas bag technique will be employed to measure patient oxygen consumption. This method provides a simple and cost effective means of measuring energy expenditure. The results will be expressed as rate of oxygen uptake and net oxygen cost.

Results—Validation of mechanical energy velocity measurement methods is nearing completion. Calibration experiments of laboratory fabricated hotwires were performed and showed their feasibility for the project. Commercially manufactured hotwires were purchased. They are currently being calibrated and integrated onto a prototype AK pros-

thesis. Initial tests indicate that they will provide good directionality and magnitude of velocity of limb segment. A data acquisition system is currently being configured based upon the laboratory computer. This will enable the data from the hotwire to be acquired in real-time by the computer. Analysis of the data will then be performed according to project protocols.

Energy consumption measurement validation is nearing completion. Measurements are being performed and analyzed on normal controls. Results thus far correlate well with published data.

Materials for prostheses construction were procured and delivered to a certified prosthetist. A prototype AK prosthesis was fabricated for evaluation purposes. In addition, the hotwires are being integrated onto the prosthesis to accomplish velocity measurements.

Future Plans—AK amputee patients are currently being recruited to participate in the research project. Initial response by recruitment survey has indicated a desire by many patients to evaluate a “light weight” prosthesis. Selection criteria for patients will be based upon current physical condition and overall condition of stump and prosthesis. Energy cost determinations combined with gait parameter evaluation, and motion analysis will be used to determine the effects of mass, mass distribution and motion. Ultimately this information will be used to optimize prosthesis weight and weight distribution.

Automated Fabrication of Lower Extremity Prosthetic Sockets

James Williams, M.D., and Thomas A. Krouskop, Ph.D.

Veterans Administration Medical Center, Houston, TX 77211 and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The goal of the project is to explore the feasibility of using computer-aided design (CAD) techniques to reduce the hand labor associated with above-knee prostheses.

Progress—The methodology for using computer-aided design to predict the shape of a socket for use in an above-knee prosthesis has been developed. Shape data that characterizes the shape of the stump have been collected from 15 above-knee amputees using the shape-sensing equipment that was developed as part of this project. The methodology for the shape data collection is currently being refined to make it easier to use in the clinical environment. Techniques are being developed to permit the machine to recognize movements of the limb that may occur during the data collection. This refinement will be used to alert the operator to the need for repeating the data collection process. A computer control ultrasonic instrument has been developed to quantify the mechanical properties of the soft tissue comprising the stump. This system has been used to collect data on 15 above-knee amputees and many normal volunteers.

We are currently studying how many readings must be taken to accurately characterize the tissue and we are studying which points on the stump are most critical in calculating the rectified socket shape. As part of this activity, we are studying how large

the tissue volume that is scanned needs to be to produce repeatable data. We are also developing a support system to reduce the tendency to contract the muscles during a data collection session. The shape and material property data have been used to generate socket molds for 6 amputees. At this time, we are modifying the algorithms to select either a quadrilateral brim or NSNA brim.

Future Plans/Implications—Sockets for an additional 14 amputees will be fabricated to study when our computer-aided design technique can be successfully used to fit the prostheses. We plan to continue the instrument refinement and develop proper instruction manuals for the shape data collection and the material characterization technique.

Publications Resulting from This Research

Salvage of Amputation Stumps by Secondary Reconstruction Utilizing Microsurgical Free Tissue Transfer. Shenaq S, Krouskop T, Stal S, Spira M, *Journal of the American Society of Plastic and Reconstructive Surgery*, 79(6):861-870, June 1987.

A Pulsed Doppler Ultrasonic System for Making Noninvasive Measurements of the Mechanical Properties of Soft Tissue. Krouskop T, Vinson S, *Journal of Rehabilitation Research and Development*, 24(2):1-8, Spring 1987.

Computer-Aided Design of a Prosthetic Socket for an Above-Knee Amputee. Krouskop T, Muilenberg A, Dougherty D, Winningham DJ, *Journal of Rehabilitation Research and Development*, 24(2):31-38, Spring 1987.

C. Upper Limb

1. General

Improved Upper Limb Prosthetics Development Program

Dudley S. Childress, Ph.D.

Veterans Administration Medical Center, Chicago, IL 60611

Sponsor: VA Rehabilitation Research and Development Service (Project #XA306-2DA)

Purpose—Progress in the development of new technologies, whether for general use in society or for specialized use by persons with amputations, requires continuous effort. No significant advances in the field are possible without active, aggressive investigations that continually question current practices and that continually try to develop improvements. Satisfaction with the status quo inhibits progress by its very nature. The technologies available for upper limb prostheses do not seem good enough at this time for status quo to be a viable operating option. Therefore, this upper limb prosthetics development program intends to create new upper limb components in response to clinical needs observed by the investigators in their attempts to effectively fit a wide range of upper limb amputees.

The program consists of two parts. Project 1 concerns the development of powered prosthetic fingers (including thumb); a new idea in powered prehension prostheses. We believe this new development will permit expanded versatility in prosthetic hand rehabilitation, by permitting routine customization of powered hand configurations, and by encouraging the conservation of the wrist joint in severe partial hand amputation problems. We believe it is possible to fit partial hand amputees with functional, cosmetic, and protective prostheses that are also self-suspended and self-contained and that allow full functional positioning of the prosthesis by the wrist and arm. Powered prosthetic digits for the hand can be used soon in common ways such as by myoelectric control of several digits in partial hand, wrist, and below-elbow fittings. In the longer view, these components may permit the control of individual digits, and help in studies of how individual finger control can be integrated with the body to produce functional, coordinated patterns of prehension activity.

Project 2 concerns the development of electro-

mechanical joint locking/unlocking components and a cable recovery mechanism for the improvement of body-powered and hybrid prostheses for upper limb amputees. Upper limb amputees, particularly those with high-level bilateral limb loss, frequently can make good use of a body-powered, cable-drive prosthesis. With proper harnessing, and with currently available components (sometimes modified), an amputee can use one cable to control the useful operations of opening-closing of a terminal device, wrist supination-pronation, wrist flexion-extension, and elbow flexion-extension. However, this control requires that the amputee be able to lock and unlock each joint and that each joint have movement in one direction (in opposition to the cable-operated direction) that is activated by a spring or by gravity. Joint locks currently used are frequently difficult to operate mechanically and the control sites for their operation are sometimes hard to efficiently incorporate into the prosthesis. We plan to develop locking and unlocking joint mechanisms that require little effort to operate and that can be easily interfaced with the amputee. Although this project was stimulated by problems of the high-level bilateral upper limb amputee, the results may also be of much significance to the more common unilateral above-elbow amputee, because an electrically activated elbow locking/unlocking mechanism may greatly improve proficiency of operation of this prosthesis, allow a wide variety of control options (e.g., electrical switches or myoelectric activation from biceps brachii), and simplify harnessing.

We also propose developing a positive locking shoulder joint that will use electromechanical locking/unlocking to enable a high-level amputee to position the free swinging shoulder joint and to positively lock it in favorable positions when so desired.

An amputee using a body-powered system often

uses up available cable excursion, especially when fully flexing the elbow, and consequently has little remaining excursion, along with an inefficient body position, for cable operation of his terminal device when in this position. We propose to develop a practical cable recovery unit (an improvement upon

one that was developed a number of years ago but which is not now available) that will allow the amputee to regain his excursion and his best force operating range after using body power to flex the elbow.

Cosmetic Covers for Upper Extremity Prostheses (Male/Female)

Robert A. Erb, Ph.D., and Lawrence Cerullo

Franklin Research Center, Philadelphia, PA 19103 and Veterans Administration Medical Center, Philadelphia, PA 19102

Sponsor: VA Rehabilitation Research and Development Service

Purpose—An objective of this program is to develop realistic and durable cosmetic covers for hand and arm prostheses for men and women. Advanced materials and techniques have been used in achieving this objective, including the concept of using the subject's remaining hand, where possible, for mirror-image replication.

Progress—Activities and results include the following:

The approaches developed for primary molding of the hand use addition-cure silicone rubber (supplied with an inline mixer) to provide highly detailed, dimensionally stable molds. For split molds, "zip-strip" devices were developed to minimize seams. These are preformed, flexible silicone-rubber strips (straight or curved) with hemispherical or interlocking keys on a separator-treated face. For evertable molds, a rapid-curing, silicone backup material was developed to provide greater tear resistance than the other rapid-cure silicones.

Techniques were demonstrated for using, in part, a subject's remaining hand as a master for a cosmetic cover. Involved here was the use of a 3-D reversing pantograph for carving the general shape of the hand and arm. Wax casts of the subject's fingers, with other wax overlays cast in silicone rubber molds, plus texturized bridging between areas, provide the reversed master from which a final mold can be made.

A concept was made for an adjustable-size internal skeleton for cosmetic covers. Active-hand prototypes were made using pivoted, square telescoping tubing with polyester film tendons for flexion and

torsion springs at each joint for extension. The use was demonstrated of two tendons per finger (with different phalanx attachment points), sequentially actuated by one linear movement. The single-control prototype hands (thumb plus two moving fingers) show excellent dexterity and conformability in grasping objects of various sizes and shapes.

Means were designed for quantitative pigmentation for intrinsic coloration. One approach involves color triangles for covering the entire skin-tone region in Munsell color space. Another approach involves making silicone-rubber swatches with translucent-over-opaque layers covering selected colors of greatest interest.

Materials approaches used for flexible final molds were: 1) castable polyurethane; and, 2) silicone rubber with a surfactant-solution release agent applied. The latter was used for evertable molds for making a cosmetic cover directly from a donor mold (single use with present technology). Demonstration cosmetic covers (male and female examples) were fabricated with multilayer intrinsic coloration of addition-cure silicone elastomer. Good realism was achieved. A finished below-elbow prosthesis was made with a cosmetic cover from an evertable donor mold with a partial side seam (zip-strip). Kevlar-reinforced epoxy was used for the socket.

Future Plans/Implications—This program was completed in April 1987. A proposal has been submitted for a follow-on project to include continued development and demonstration efforts, technology transfer and training, and applications to active hands and to lower extremity prostheses.

Design of Prehension Systems for Upper Limb Amputees

Craig W. Heckathorne, M.S.E.E.; Dudley S. Childress, Ph.D.; Edward C. Grahn, B.S.M.E.; Hal Krick, C.P.
Veterans Administration Lakeside Medical Center, Chicago, IL 60611 and Prosthetics Research Laboratory,
Northwestern University, Chicago, IL 60611

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The overall objective is to increase the variety of powered prehensile devices available to persons with upper limb amputations. Specifically, we are proposing: 1) new utilitarian prehensile fingers which are not based on the traditional hook shape; 2) a cosmetic hand with high performance characteristics; and 3) a utility-hand which would serve as a compromise between utilitarian and cosmetic designs but would have advantages of both.

Progress—Refinements of the power-base actuator for the prehension devices has been completed. Several concepts for the utilitarian prehensile fingers and for the utility-hand, developed in cooperation with an industrial design team, are currently being evaluated. Final designs will be carried through to prototype fabrication and will be field-evaluated by persons with amputations below the elbow.

The Use of CAD/CAM in the Design and Development of a Range of Prosthetic Components for the Upper Limb

David Gow; Parviz Moghaddam; T.D. Dick; J.L. Murray
Bioengineering Centre, Princess Margaret Rose Orthopaedic Hospital, Edinburgh EH10 7ED, Scotland, UK and
Department of Mechanical Engineering, Heriot Watt University, Riccarton Campus, Currie, Edinburgh,
Scotland, UK

Sponsor: Committee on Research for Equipment for the Disabled, Scottish Home and Health Department

Purpose—The aim of this project was to use the design and fabrication facilities of the CAMX CAD/CAM (computer-aided design/computer-aided manufacture) system to eliminate model building time in the development of upper limb prosthetic components. The idea of developing modular upper limb prosthetic components, which has now been adopted as the main theme of research in Edinburgh, has led to a joint project with the department of mechanical engineering at Heriot Watt University in Edinburgh. Their expertise in the use of solid modeling CAD/CAM techniques is being utilized in the development and fabrication of a range of prostheses from child to adult.

The main objective of this project was to eliminate a large amount of the model building time normally associated with prototyping. A midrange size of prosthesis would be built and the results scaled up and down to produce a "jigsaw" of pieces covering all sizes of the range. The components would be manufactured using the CAM facilities at the university and would allow a greatly enlarged trial number of patients to be fitted than could conceiv-

ably have been envisaged using conventional machining resources.

Progress—The design of a midrange hand size (half way between smallest child and largest adult size) was achieved using conventional design techniques. The CAD facility was used to scale up and down the variables necessary to achieve a full range of sizes (six in all). The CAM resource was then used to manufacture the various prosthetic components. In addition, the CAD facility was used to model the internal hand volume within which it was permissible to place structural and power components.

Preliminary Results—Initially, we have achieved the manufacture of power modules for body-powered and externally-powered components as well as associated structural parts.

Future Plans/Implications—It is anticipated that the complete "jigsaw" of pieces, from which we hope

to be able to assemble any one of the six sizes of prosthesis of the range, will be manufactured by the

fall of 1987. A full scale evaluation of the prostheses will then be affected.

Further Research into the Use of Room Temperature Vulcanizing (RTV) Silicone Rubber as a Cosmetic Glove Material for Upper Limb Prostheses

David Gow; C.M. Moodie; K. Quinn

Bioengineering Centre, Princess Margaret Rose Orthopaedic Hospital, Edinburgh EH10 7ED, Scotland, UK

Sponsor: *Committee on Research for Equipment for the Disabled, Scottish Home and Health Department*

Purpose—The aim of this study is to quantify and evaluate the relevant mechanical properties of various commercially available room temperature vulcanizing (RTV) silicones and to optimize the silicone for use with upper limb prostheses.

The Bioengineering Centre has developed a process for manufacturing complete cosmetic gloves for functional and cosmetic prostheses from silicone rubber. The Centre has now gained experience over the last eight years in fitting over forty patients and results show that the average life of these cosmetic gloves is about three months. Despite much improved cosmesis and cleaning properties, the gloves tend to fail catastrophically rather than degrade gradually. Therefore, this research is intended to improve the strength and durability of silicone rubber prosthetic coverings.

Progress—A survey of available RTV silicones has been undertaken and those suitable in terms of pigmentability and handling strength determined. Ten silicones in all have been isolated for research purposes. Mechanical testing in the form of tensile, tear and wear tests is being undertaken on "0" ring samples of the materials.

Preliminary Results—Initial results indicate that an increase in mechanical strength of at least 30 percent can be achieved with no loss of cosmesis.

Future Plans/Implications—It is intended to complete the testing on all the silicone samples, but use preliminary results to manufacture gloves for patient/laboratory testing to gain valuable field results before the expiration of this research in July 1988.

Research into a Modular Prosthetic Development for the Upper Limb

David Gow

Bioengineering Centre, Princess Margaret Rose Hospital, Edinburgh EH10 7ED, Scotland, UK

Sponsor: *Lothian Health Board*

Purpose—The objective of this study was to develop a useful system of interchangeable components for control, cosmesis, power and structure of artificial upper limbs. From the previous experience gained in the manufacture of body powered prostheses and externally powered prototype limbs it was decided that a series of components could be devised which were interchangeable between different sizes and different power regimes. The aims of this work are to develop six sizes of prosthesis from child to adult male. The work is to split into four areas: cosmesis, control, power, and structure. Cosmesis is to be based on room temperature vulcanizing silicone

elastomer. Control is to be based on interchangeability between control regimes such as extended physiological proprioception (EPP), electromyogram (EMG), or switch control. Power is based on body power and miniature gearboxes and 0.5 to 3 watt D.C. motors powering ballnut or ballscrew actuators. Structure is to be based upon interchangeability of components between sizes and power types, i.e., body-powered hand structure is identical to electrical-powered hand structure.

Progress—Prototype hand components for the mid-range hand size (size 3) were built and tested. Critical

components which could be used in all six hand sizes were identified and dimensions finalized. In addition, six different types of actuator (three mechanical and three electrical) were built and evaluated. Once the basics of power and structure were determined, various control methods were tested for incorporation into the final design. At this stage, design modifications were made to allow for a good cosmetic result to be achieved.

Preliminary Results—Preliminary results are very encouraging. Working prototypes of both body-powered and electrically-powered hands have been built and are efficient and controllable. Final modifications to achieve optimum cosmesis are presently in work. One trial patient has been fitted to determine controllability. Patient response was enthusiastic and encouraging.

Improvement of Body-Powered Upper Limb Prostheses

Maurice LeBlanc, MSME, CP

Children's Hospital at Stanford, Palo Alto, CA 94304

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The goal is to improve the acceptance and use of body-powered upper limb prostheses by arm amputees in the USA. The objective of this project is to improve conventional arm prostheses by means of a hydraulic force transmission system to replace the present cable control system.

Progress—A hydraulic control system has potential advantages of allowing the improvement in function, comfort and appearance of conventional arm prostheses. The first and major challenge is to design and develop a system which can be placed inside the prosthesis where it does not show and interfere with clothing.

Preliminary Results—A proof-of-concept external hydraulic control system has been built and tested encouragingly with six amputees. An internal hydraulic control system has been built and tested in the laboratory and found to be an unsuccessful solution due to the size constraints of packaging all the hardware inside the prosthesis. (Arm amputees want the prosthesis to be smooth and soft on the outside.)

Future Plans/Implications—Design and development of a suitable hydraulic control system is continuing

in an attempt to find a satisfactory solution. Because the force and excursion requirements of the prehensor are critical to the control system and because of renewed interest in voluntary closing operation, new designs of prehensors are being explored. As well as continued efforts on hydraulic control systems, a parallel effort will be applied toward: 1) the development of a new elbow-extension controlled below-elbow prosthesis which eliminates the shoulder harness; 2) the improvement in technology of present cable systems; and 3) evaluation of new designs of prosthetic prehensors.

Publications Resulting from This Research

Body-Powered Upper Limb Prosthetics. LeBlanc M, *Abstracts, ISPO V World Congress*, June 29-July 4, 1986.

Study of Body-Powered Upper Limb Prostheses in Europe. LeBlanc M, Report of Fellowship by International Exchange of Experts and Information in Rehabilitation, World Rehabilitation Fund, September 5, 1986.

Do We Need a Prehensor Which Is Neither Hook Nor Hand? LeBlanc M, Parker D, Nelson C, *Proceedings of the Tenth Annual RESNA Conference*, June 19-23, 1987.

Making the Case for Body-Powered Upper Limb Prostheses. LeBlanc M, *Proceedings of the Tenth Annual RESNA Conference*, June 19-23, 1987.

New Designs for Prosthetic Prehensors. LeBlanc M, Parker D, Nelson C, *Proceedings of the Ninth International Symposium on External Control of Human Extremities*, August 31-September 5, 1987.

Development of a Cosmetic Functional Prosthesis for Children

David Gow

Bioengineering Centre, Princess Margaret Rose Orthopaedic Hospital, Edinburgh EH10 7ED, Scotland, UK

Sponsor: REACH (*The Association for Children with Artificial Arms*)

Purpose—The purpose of this research was to design, develop and fit a cosmetic, functional prosthesis for children. The experience of the Bioengineering Centre in producing functional prostheses with enhanced cosmesis has, to date, mainly been confined to adults. The knowledge gained has now been applied to the construction and testing of a miniature electric hand for children.

The research was aimed at building a small, responsive prosthesis with silicone glove cosmesis. In addition, research into battery systems and modular components would be attempted.

Progress—Prostheses were built using miniature motors and gearboxes mounted transversely to the wrist. The actuators were tested in the laboratory, undergoing a minimum of 10,000 opening and closing cycles.

Preliminary Results—The prostheses produced were remarkable for their compactness, seeming in effect

to be no more than “powered knuckles.” The first prototype was tested on a young transcarpal amputee. The patient used flexion and extension to control opening and closing; control was good and repeatable. The length of the prosthesis was an excellent match to the remaining natural hand, and cosmesis was excellent.

The second prototype produced a slightly higher grip performance of 13N (3 lbs force) at the fingertips, but was in fact more compact than even the previous model. It would appear that all levels of amputation from just-proximal to trans-metacarpophalangeal joints could be accommodated with no lengthening effect.

Future Plans/Implications—Different control regimes, e.g., extended physiological proprioception single-switch control, will be tested on these prototypes and more patients will be fitted. In addition, research is on-going into the use of smaller, more compact battery systems.

Research Into the Use of a Shape Memory Alloy as a Power Assistive Component for Upper Limb Prostheses

David Gow

Bioengineering Centre, Princess Margaret Rose Hospital, Edinburgh EH10 7ED, Scotland, UK

Sponsor: Women's Royal Voluntary Service

Purpose—This research is designed to investigate the thermal properties and force generating capacity of shape memory alloy (SMA) and its usefulness as a power component in upper limb prosthetics.

Progress—The properties of the alloy of nickel and titanium, called nitinol, are well documented; the material exhibits the property of recovering from large mechanical strains and generating a large recovery force. This recovery is triggered at the transition temperature which is dependent on alloy composition and heat treatment. Maximum recovery forces of around 600 N per mm square of cross-sectional area can be achieved.

The heating and cooling of shape memory alloy wire, 0.5mm and 1.0mm in diameter, is being investigated. The temperature of the wire is elevated using electroheat and cooled under various regimes, namely, natural convection, forced convection and heat sinking. Actuators operating the prehensors of a prosthetic device have been constructed using nitinol wire and electric motors. Also, a purely mechanical prosthesis has been constructed.

Preliminary Results—Initial results are encouraging and suggest that the combination of a lightly geared electric motor and nitinol transmission member can give both high speed and large stall force capability.

In addition, the wire has been included in a wrist-operated prosthesis to allow electromechanical power assistance in a severely restricted space, which would have precluded the use of a conventional electromechanical device.

Future Plans/Implications—It is intended to evaluate the long-term performance of prostheses incorporating SMA and to optimize the control regime using bench experimental models.

C. Upper Limb

2. Below-Elbow

Below-Elbow Prosthetic System

Dudley S. Childress, Ph.D.; Edward C. Grahn; John S. Strysik
Prosthetics Research Laboratory, Northwestern University, Chicago, IL 60611

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—The objective of this project is to develop a below-elbow prosthetic system with prehensor (hook/hand) interchangeability and easily removable modular components. The components consist of the prehensors: a NUVA Synergetic Prehensor and an electric hand, the signal processor circuit board, the active electrodes, a ground electrode, a battery pack, and a wrist connector that provides the mechanical and electrical connection between the prehensor and forearm.

Progress—The Veterans Administration Rehabilitation Research and Development Evaluation Unit has purchased 20 systems for clinical evaluation through VA Medical Centers. Commercial availability of this system to the consumer, through a prosthetics facility, is expected in the near future. This laboratory will continue to work with the manufacturer in an advisory capacity.

A Study of the Range of Motion of Human Fingers with Application to Anthropomorphic Designs

Nitish V. Thakor, Ph.D., and Jeffrey C. Becker
Biomedical Engineering Department, The Johns Hopkins School of Medicine, Baltimore, MD 21205

Sponsor: *Nursing Home Program Project of the The National Institutes of Health*

Purpose—The multi-fingered human hand serves as a model for the design of anthropomorphic manipulators and prosthetic devices. Our objective is to study the motion of the human hand and fingers. We propose to conduct experiments and develop a model to describe the range of motion of a human finger. We hope that this can guide us in the design of anthropomorphic manipulators. We hope to demonstrate the technique with a prototype design.

Progress—We studied the anatomy of the human finger, comprised of multiple joints, and tendons

actuating the movement of these joints. Based on the modeling studies and data obtained from cadaver fingers by others, we developed equations describing tendon displacement from the rotation of two joints. These data are presented in a range of motion plot. We obtained range of motion plots for normal and disabled fingers.

Preliminary Results—We have presented a technique to analyze the range of motion and capability (including) disability of human fingers. We have developed a prototype of a tendon-based finger. This

prototype uses shape memory alloy actuator as a tendon. Its design is preliminary because, at the present time, it is quite limited in performance.

Future Plans/Implications—Our future plans are to develop a model and an assessment technique for multiple, interacting fingers. This is important in fully understanding the dexterity of human fingers. Our prototype is currently quite limited because it

has a single tendon, and the SMA actuator is quite inefficient and sluggish. We hope to improve the design of the tendon-based actuators used in anthropomorphic fingers.

Publication Resulting from This Research

A Study of the Range of Motion of Human Fingers with Application to Anthropomorphic Designs. Thakor NV, Becker JC, *IEEE Transactions of Biomedical Engineering*, to be published, 1987.

Powered Upper Extremity Prosthetics Research and Development Project: Development of Child-Size Electromechanical Hands

M. Milner, Ph.D., P.Eng., C.C.E. and R. Galway, M.D., F.R.C.S.(C)
Hugh MacMillan Medical Centre, Toronto, Ontario M4G 1R8

Sponsor: *Variety Club of Ontario, Tent #28*

Purpose—The objective of this study was to develop three sizes of hands to cover the age range from 2 to 12 years old. Presently, two sizes, the VV03 and VV2-6 hands, have been developed and are now being marketed. The final size is to be completed this year. This hand is 20 percent larger than the VV2-6 hand.

Progress—A new design of the Size #2 hand was developed and a prototype built and tested. This hand is to address the needs of children between 7 and 12 years old. The main feature of this design is the utilization of a friction drive system in order to

reduce the noise level. Continuous bench testing showed no consistent running current. This was investigated. The friction drive unit was redesigned and an updated prototype was fabricated and tested. This model was cycle-tested continuously on the bench for 250,000 cycles without any problems. Most of the documentation is completed and some details have been released for production.

Publications Resulting from This Research

A New Variety Village Electromechanical Hand for Child Amputees Less Than Two Years of Age. Al-Temen I, Mifsud M, Spencer J, Milner M, *Journal of the Association of Children's Prosthetic-Orthotic Clinics*, 1986.

An Examination of Hand Amputees and Two Prosthetic Options

L. Fay (Student), B.Sc.O.T.
Hugh MacMillan Medical Centre, Toronto, Ontario M4G 1R8

Sponsor: *None Listed*

Purpose—This study has the following objectives: 1) to identify possible demographic and amputation characteristics of the child hand amputee which may affect prosthetic choice and use; 2) to determine the types of prostheses used by the child hand amputee, the extent of use, reason for use and functional gains; and, 3) to gain information on prosthetic satisfaction and areas of concern.

Progress—A questionnaire was developed by the principal investigator and mailed to 38 hand ampu-

tees presently on active cases at the HMMC. Included with the questionnaire was an information sheet and consent form. The data obtained were categorized, coded, and analyzed. Nonparametric analyses were conducted, consisting of frequency and percentage distribution.

Results—The results indicated that those amputees surveyed used either a spatula, standard below-elbow, switch electric or myoelectric prosthesis. Use of a specific type of prosthesis was not de-

pendent on type of amputation. The myoelectric prosthesis was used predominantly, particularly among the younger subjects surveyed. Early prosthetic fitting was deemed important for positively influencing future prosthetic use. Prostheses were reported to be primarily used to increase function as opposed to cosmetic reasons. Functional gains,

however, were reported to be marginal. Prostheses were used passively by the majority of the sample, possibly as a result of many reported difficulties associated with the prosthetic fitting of congenital, unilateral hand amputees. These difficulties were outlined. Implications for practice and research were discussed.

C. Upper Limb

3. Above-Elbow

Position-Servo Control of Upper Limb Powered Prostheses

Craig W. Heckathorne, M.S.E.E.; Dudley S. Childress, Ph.D.; Hal Krick, C.P.; Lew J. Leibowitz, B.S.E.E.; John Stryzik

Veterans Administration Lakeside Medical Center, Chicago, IL 60611 and Prosthetics Research Laboratory, Northwestern University, Chicago, IL 60611

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Experience has shown that users of powered multi-joint prostheses must give considerable attention to the control of these prostheses. The effective use, i.e., with low mental loading, of more than two powered joints in coordinated movements does not appear possible using “velocity-control” approaches, e.g., switch and myoelectric controllers.

We are proposing to implement a force-actuated position-servo controller, coupling an anatomical joint(s) and a prosthetic joint(s), as a means of achieving improved control of multi-joint powered prostheses. This type of controller is based on Simpson’s concept of extended physiological proprioception (epp). Position and velocity of the prosthetic joint are controlled by the anatomical joint. And, because of the coupling between the joints, the user is constantly aware of the position and velocity of the prosthetic joint through the propri-

oception of the anatomic joint. The effectiveness of this control has been demonstrated empirically in Simpson’s applications to gas-powered prostheses and experimentally in comparisons with velocity control of electric-powered prostheses.

Progress—We are preparing to initiate a field evaluation of a prototype epp-controller, which uses a commercially available thick-film force-sensitive resistive material to transduce the force in the cable coupling the user to the prosthesis. Our plans are to fit an individual having an above-elbow amputation with a Hosmer NYU elbow modified for the prototype controller. Methods of supporting and harnessing the system are under development. The initial fitting will have only the electric elbow controlled by the epp-controller, with the terminal device under myoelectric control.

Implementation of Extended Physiological Proprioception for Prosthesis Control

William G. Winter, M.D. and Lawrence E. Carlson, D.Eng.

Department of Orthopaedic Surgery, Veterans Administration Medical Center, Denver, CO 80220 and Department of Mechanical Engineering, University of Colorado, Boulder, CO 80309

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Extended physiological proprioception (EPP) is a control concept that has demonstrated certain advantages for the position-control of prostheses. The goal of this project is to control a Utah Arm with EPP, fit it to an above-elbow amputee, and evaluate its performance.

Progress—The Utah Arm with EPP control has been fitted to the test subject at the University of Colorado Health Sciences Center in Denver, using a transparent check socket and a figure-eight suspension/control harness. Initial attempts to control the arm were very successful; the amputee could immediately position the elbow where desired with little ambiguity.

Mechanical failure of a cable attachment halted the experiment, but that problem is being corrected by redesign of that portion of the transducer. In addition, semiconductor strain gauges will be added to reduce current drain in the system.

Future Plans—When the cable attachment has been reinstalled, the amputee will visit our laboratory at the University of Colorado in Boulder, where he will perform random tracking and blind positioning tests while a computer data acquisition system monitors his performance. Three variables will be monitored: elbow angle, input displacement, and feedback displacement. The tests will be performed using both EPP and myoelectric control for comparison.

Preliminary studies of various candidates for an optical transducer have been completed and a prototype is in the design stage. The plan is to use the new transducer to control a Boston Elbow, which will be furnished by Liberty Mutual Insurance Company. A suitable subject for these trials has been located. Fitting will commence when the new system is operational.

Extended-Limb Prostheses

Edward C. Grahn, B.S.M.E., and Hal Krick, C.P.

Rehabilitation Engineering Program, Northwestern University, Chicago, IL 60611

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—The objective of this project is to determine if, under some conditions, simple extensions of the limbs of persons with high level, upper limb amputations can be more effective functional tools than conventional types of prostheses.

Progress—One concept is a prosthetic socket with a device attached to its immediate distal end that will enable a person with an above elbow amputation to write more easily. This would utilize a writing device that is now commercially available but which is intended for a hand orthosis. It comes with three interchangeable tips that allow the user to choose among a pencil, a pen, and an eraser.

The first subject for a clinical evaluation of this

concept is a young man, 30 years old, with traumatic amputations above elbow bilaterally and hip disarticulation on the right side. He was fitted bilaterally with above elbow prostheses; a lower limb prosthesis allowed the subject to walk quite well. A prosthetic socket with a writing device attached to the distal end was fabricated for his right (dominant) side. This is intended to replace the standard prosthesis only when the subject wants to write; writing is its only function. The subject was able to write legibly, in fact he stated that it resembled his hand writing prior to the accident that caused the amputations. He was readily able to change tips to choose between pen and pencil. He found the device useful and wanted to keep this prosthesis for use at home.

The next step in development is to incorporate this device into a standard prosthesis so that the user does not require someone to change the entire prosthesis whenever he wishes to write. Two schemes have been developed. The first scheme will require a simple disconnect mechanism that can be operated by the person wearing the prosthesis to permit easy removal of that part of the prosthesis distal to the writing device. The mechanism must also contain electrical contacts when electrical components are distal to this point and electrodes or switches and/or battery cables are proximal. The disadvantage of this scheme is the dexterity required to detach and reattach the distal prosthesis. The advantage is that with the distal portion removed, the user has good

visibility of the writing device.

The second scheme is to provide a second hinge on the anterior aspect of the humeral section which is proximal to the elbow mechanism of the prosthesis. Unlatching the second hinge would allow the user to flex the elbow mechanism and forearm as a unit against the humeral section, exposing the writing mechanism. The advantage of this scheme is that no portions of the prosthesis need be completely separated, and unlatching would not require any dexterity. The disadvantage is that the flexed portion would limit visibility of the writing device.

Future Plans—Both schemes will be clinically evaluated on amputee subjects.

An Electric Artificial Limb for Children Without Limbs

Craig W. Heckathorne, M.S.E.E.; Dudley S. Childress, Ph.D.; Edward Grahn, B.S.M.E.; Hal Krick, C.P.; John Stryzik

Rehabilitation Engineering Program, Northwestern University, Chicago, IL 60611

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The objective is to develop an artificial arm that can be used by children who are born without arms. To provide effective control of the arm, we will be implementing a force-actuated position-servo controller based on Simpson's concept of extended physiological proprioception (epp).

Progress—A prototype epp-controller has been developed and implemented on the NU/Michigan Arm. This arm is a child-size prosthesis (for children ages 3-6 years) developed by our laboratory for the Area Child Amputee Center (ACAC) in Grand Rapids, Michigan. Four of these arms have been constructed for the ACAC and are presently controlled with

switches.

The epp-controller is configured as a force-actuated position control system. The force in a cable coupling the child's shoulder to the forearm of the prosthesis controls the direction of movement of the forearm and, proportionally, the width of the drive pulses delivered to the elbow motor. The position of the child's shoulder determines the position of the forearm relative to the humeral component. A force-sensitive resistive material is used to transduce the force in the coupling cable. Methods of mounting and harnessing the prosthesis are under investigation preliminary to a clinical fitting.

Quantification of the Functional Capability of Upper Extremity Amputees

Neville Hogan, Ph.D.

Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The goal of this project is to develop and apply a technique for quantification and measurement of the upper-extremity functional capability of able-bodied and disabled persons. Quantifying the disability due to upper-extremity amputation is the primary concern, though the techniques developed

may have application to other upper-extremity disabilities. The techniques which have been developed are practical and have been derived from a deep understanding of the kinematic, dynamic, and neural aspects of upper-extremity motor behavior. Performance is measured on specific tasks that repre-

sent the functional role an upper-extremity prosthesis can realistically be expected to play.

Much of the prior work on prosthesis assessment has focused on an amputee's ability to position or move a prosthesis, but to be of functional benefit, a prosthesis must allow an amputee to grasp and wield objects—to contact objects and to interact successfully with them. Therefore we have focused on contact tasks.

To quantify performance precisely, we have investigated one simple but representative task extensively: turning a crank in a vertical plane. Turning a crank is representative of the contact tasks an amputee may need to perform (e.g., opening a drawer or opening a door). These tasks can be difficult to perform using current artificial limbs as the mechanical joint (e.g., the elbow) must be coordinated with the natural joints (e.g., the shoulder). An analysis of the mechanics of crank turning showed that there are critical points along the crank trajectory where shoulder/elbow coordination is essential. At these points, due to the geometry of the arm/forearm/crank linkage, it is not possible to drive the crank using the shoulder or elbow joint alone. Coordination of the two is required.

Progress—In the past year we have applied these techniques to assess the importance of elbow motion for upper extremity function. Much effort has been devoted to the development and refinement of elbow prostheses. Yet there are many possible factors contributing to an above-elbow amputee's disability: damage to the nervous system, sensory loss, loss of several mechanical degrees of freedom, poor mechanical performance of the prosthesis, and poor interfacing between amputee and prosthesis are among the prominent candidates. Is a controllable, functioning elbow important for an amputee, or have elbow prostheses been pursued simply because the elbow is an easy joint to engineer?

In this project we have attempted to determine how much of the observed functional deficiency can be attributed to the performance of an elbow prosthesis itself. To do this we have developed an arm brace (similar to an orthosis) which allows us to add passive dynamic loading to an intact arm. With this device we can approximate, in an intact arm, the relation between muscular activity and the arm motion an amputee using a myoelectrically controlled prosthesis has to deal with. For example, the maximum speed of intact elbow motion can be restricted to that of the prosthesis.

Preliminary Results—We then compared the ability of 1) an intact arm braced in this way, 2) an unencumbered intact arm, and 3) an amputee using a Boston Elbow (a myoelectrically controlled, externally powered, electromechanical elbow prosthesis) to perform the crank-turning task. We found that (as expected) the performance of the unencumbered intact arm was significantly different from that of the prosthesis. We also found that the performance of the braced intact arm was essentially indistinguishable from that of the prosthesis.

The significance of this result is that by simply degrading the mechanical performance of an intact elbow, we could reproduce the movement strategy and kinematic performance of an amputee using a prosthesis. Although factors such as neural damage, sensory loss, etc., are undoubtedly important contributors to an amputee's disability, the difference in mechanical performance of the elbow alone is sufficient to account for the observed differences between the performance of the unencumbered intact arm and the prosthesis. We conclude that a controllable, functioning elbow is important for an upper-extremity amputee.

Publications Resulting from This Research

- Quantitative Functional Assessment of Elbow Prostheses.** Abul-Haj, C, Hogan N. *Proceedings of the 39th Annual Conference on Engineering in Medicine and Biology*, 100, September 1986.
- Multivariable Mechanics of the Neuromuscular System.** Hogan, N. *Proceedings of the 8th Annual Conference of the IEEE Engineering in Medicine and Biology Society*, 594-598, November 1986.
- Moving Gracefully: Quantitative Theories of Motor Coordination.** Hogan N, Flash T, *Trends in Neurosciences*, 10(4):170-174, April, 1987.
- Controlling Multi-Joint Motor Behavior.** Hogan N, Bizzi E, Mussa-Ivaldi FA, Flash T, *Exercise and Sport Sciences Reviews*, Vol. 15, 1987.
- Coordinating Multi-Joint Motor Behavior.** Hogan N, *Proceedings of the ASME 1987 Biomechanics Symposium*, AMD, 84:383-386, Cincinnati, OH, June 1987.
- Quantitative Assessment of the Importance of Elbow Prosthesis Dynamic Behavior in the Performance of Manual Tasks.** Hogan N, Miller C, *Proceedings of the RESNA 10th Annual Conference*, 193-195, San Jose, CA, June 1987.
- Quantitative Functional Assessment of Control Systems for Upper-Extremity Prosthesis.** Abul-Haj C, Hogan N, *Proceedings of the RESNA 10th Annual Conference*, 284-286, San Jose, CA, June 1987.
- An Emulator System for Developing Improved Elbow-Prosthesis Designs.** Abul-Haj C, Hogan N, *IEEE Transactions on Biomedical Engineering*, 1987. (In press)

Control of Metrical and Timing Precision in Human Movement

Paul J. Cordo

Good Samaritan Hospital and Medical Center, Portland, OR 97210

Sponsor: National Institutes of Health

Purpose—This study proposes to investigate central nervous system control strategies used to produce accurate movements. Control of voluntary movement is viewed in this study as a stratified process with several levels of control: 1) movements are initiated by high level construction of open-loop motor commands, which are 2) executed from a reference frame stabilized by a postural control system, and are 3) modified by sensory feedback during both command execution (“concurrent feedback”) and after movement completion using knowledge of results (“delayed feedback”). Skilled movements and isometric force production are evaluated in terms of these three control mechanisms.

Adult, human subjects will track various waveforms presented on a visual display by exerting force on a manipulandum with their elbow musculature. Comparison will be made of motor accuracy under a variety of conditions affecting: 1) the predictability of the stimulus (tracking waveform) amplitude; 2) the availability of visual feedback; 3) the degree of postural stability; and, 4) movement of the elbow joint. In most experiments subjects will track step

waveforms on an oscilloscope screen, while, in one experiment designed to distinguish between strategies subserving timing and metrical movement precision, graphical displays will be more complex. Electromyographic activity will be recorded from appropriate muscles during tracking experiments in order to characterize movement strategies at a level of peripheral neural commands to muscles. Amputees fitted with myoelectrically controlled arm prostheses will be used in several phases of this study. In one experiment, these individuals will be used as a model of the “deafferented arm,” in order to characterize this role of peripheral somesthetic feedback in the control of accurate movements in normal subjects.

In addition, a pilot experiment is proposed which directly addresses the problem of user control of multiple degree-of-freedom powered arms. It is hoped that the latter experiment will lead to the development of a large-scale research and training program for amputees at Good Samaritan Hospital and Medical Center.

Two-Degree-of-Freedom, EPP-Based Arm Prosthesis for Above-Elbow Amputees

R. Seliktar, Ph.D., and D.C. Baer, Bh.A.

Department of Mechanical Engineering and Mechanics, Drexel University, Philadelphia, PA 19104

Sponsor: National Institutes of Health

Purpose—The general intention is to develop an externally-powered mechanical arm prosthesis with two degrees of freedom. It will consist of a powered elbow and a three-finger, single-joint prehensile device.

An Extended Physiological Proprioception (EPP) control system is being developed to provide the greatest range and restoration of function. The EPP concept is based on the use of residual joints with intact proprioception to provide the subject with an intuitive knowledge of the position of the artificial arm as long as there is a rigid attachment to a member of the body. Controller circuits and trans-

ducer systems have been investigated for the control system where the arm is always directly related to the position of the shoulder joint.

Progress—Our earlier research utilized shoulder harnesses, via bicipital movement, to provide the control signals. The position sensors were mercury-filled Silastic tubing mounted to the elastic material of the harness, which failed often and had a short lifetime. Therefore, other methods were sought to determine intent for motion. A bending-type biaxial strain-gauged transducer was developed to monitor two degrees of freedom of motion of the acromion

(of the shoulder). The increased flexibility of the transducer permitted its use as a displacement gauge with negligible force resistance.

An analog control circuit was developed to use the output from the strain-gauge amplifiers as an input, and the input for the position of the artificial arm by using a linear potentiometer mounted at the elbow, which is connected in a bridge circuit (on the controller board). The control circuit acts as a null balance system and compares the output of the two bridges; the intended position of the arm and the actual position of the arm. When either signal exceeds the allowable error tolerance, the motor is activated in the proper direction until the signals are once again within the proper range.

A software system is also being developed using a Macintosh and MacADIOS interface system. This system will verify the control circuit's logic and stability and allow for other types of controllers to be tested by modelling. This interface system also provides a means to evaluate the current system for static and dynamic characteristics of operation.

Results—A preliminary evaluation of the arm system was conducted as follows: tests were performed on the transducer system, the analog control circuit, the motor drive circuit, and the whole arm. The first set of tests were performed as static calibration measurements. The transducer, strain-gauge amplifier system was tested for linearity by comparing the amount of flexion of the transducer to the voltage

output from the amplifiers. The result showed a linear relationship within 2 percent for the output of the amplifiers, which serves as the input to the control circuit. The position of the arm is monitored with the aid of the linear feedback potentiometer circuit which produces a voltage proportional to the angle of the elbow. The input voltage was compared to the position of the arm. The result was also linear within 5 percent, which meant that the control circuit was functioning as designed. The entire system was tested by comparing the flexion of the transducer to the position of the elbow, which also yielded a linear relationship within 5 percent. Dynamic tests were performed with the aid of the computer model operating in real-time. The model predicted the output of the controller circuit; whether to turn on the motor, and in which direction. The model was fed the same inputs as the controller board and at the same time. There was better than 90 percent correlation with the actual motor drive signals (which were also fed to the computer to make analysis easier).

Future Plans/Implications—The arm system currently under development has shown promise in meeting the design requirements of an extended physiological proprioception-based system or position control arm for above elbow amputees. It is compact, with good functionality, and will also be easy to learn how to use due to the intuitive nature of EPP.

Quantification Functional Assessment of Control Systems for Elbow Prostheses

Neville Hogan, Ph.D.

Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: *National Science Foundation and Whitaker Foundation*

Purpose—The goal of this project is to develop better upper-extremity prostheses. At present, our primary concern is with elbow prostheses for above-elbow amputees, though the technology developed may have application to other assistive devices. A key feature of the research program is that a major component of the effort is focused on the quantitative assessment of the functional benefits of existing and proposed prosthesis designs.

Progress—To accomplish a convincing quantitative assessment of prostheses in a laboratory environment, a new, practical technique was developed for the design and evaluation of elbow prostheses. A high-performance, computer-controlled elbow prosthesis emulator has been built. The device may be programmed to emulate the behavior of any elbow prosthesis, existing or proposed. The device is worn by an amputee and the evaluation of a prosthesis

design is based on a quantitative assessment of the amputee's ability to perform tasks representative of activities of daily living.

There are many advantages to this approach, but probably the most important is that the experiments to assess functional performance can be controlled rigorously. A broad range of prosthesis characteristics can be tested experimentally, merely by reprogramming the device. Other variables such as the weight of the prosthesis, the type of body attachment, the physical and mental condition of the amputee, the extent of sensory loss or neural damage—all remain unchanged. Modifying a single feature of a prosthesis design while keeping other variables constant allows the effect of that feature to be distinguished.

Results—Our technique for quantitative assessment of the amputee's functional performance has been described elsewhere (see the report "Quantification of the Functional Capability of Upper Extremity Amputees" in JRR&D Progress Reports 1986). To quantify performance precisely, we have investigated one simple but representative task: turning a crank in a vertical plane. Turning a crank is representative of important tasks an amputee may need to perform (e.g., opening a drawer or opening a door).

This system was used to assess the importance of the control strategies used in elbow prostheses. Most externally-powered prostheses are velocity controlled. The control signal (e.g., the position of a switch or the difference between the activities of two relevant muscles such as the biceps and triceps fragments in an amputee's upper arm) is used to determine the speed of elbow motion. One advantage of this strategy is that fixed posture may be maintained without effort. However, a drawback is that the operation of the prosthesis is quite unnatural.

A more natural strategy is impedance control. This is a new approach which has been inspired by studies of how the brain controls natural motor behavior. The difference in the myoelectric activities of two relevant muscles is used to determine the motion of the prosthesis. The sum of the activities modulates the impedance of the prosthesis, the way it moves in response to external loads. Using this control strategy, the prosthesis mimics the natural compliant behavior of the intact arm.

The ability of an amputee to perform the crank-

turning task was compared, using: 1) the new impedance control strategy; and 2) a velocity control strategy similar to that used in the Boston Elbow (a myoelectrically-controlled, externally-powered, electro-mechanical elbow prosthesis). Turning a crank can be difficult when using an artificial limb as the mechanical joint (e.g., the elbow) must be coordinated with the natural joints (e.g., the shoulder). An analysis of the mechanics of crank-turning showed that there are critical points along the crank trajectory where shoulder/elbow coordination is essential. At one of these points, the elbow reverses its motion, and cannot contribute any force to driving the crank; this must be accomplished by the shoulder. At the other point, the roles of shoulder and elbow are reversed.

When using the velocity control strategy, the amputee rapidly reversed the elbow driving torque at the point of elbow reversal. This rapid reversal required precise timing of muscle activities, and the amputee slowed down markedly near the point of elbow reversal, apparently pausing to identify the correct moment to switch. In contrast, using the impedance control strategy, the amputee could easily coordinate the artificial elbow joint with the natural shoulder joint. The motion was faster and smoother and the reversal of elbow motion was accomplished with a much more gradual reversal of elbow driving torque. Because this control strategy does not require precisely timed switching of muscle activities, the concentration required of the operator is reduced, and the amputee reported that the task was much easier to perform with this controller.

Implications—These results show that the control strategy used in a prosthesis has a major influence on its functional benefit to an amputee and that impedance control offers significant advantages over velocity control.

Publications Resulting from This Research

Quantitative Functional Assessment of Elbow Prostheses. Abul-Haj C, Hogan N, *Proceedings of the 39th Annual Conference on Engineering in Medicine and Biology*, p.100, September 1986.

Multivariable Mechanics of the Neuromuscular System. Hogan N, *Proceedings of the 8th Annual Conference of the IEEE Engineering in Medicine and Biology Society*, pp.594-598, November 1986.

Moving Gracefully: Quantitative Theories of Motor Coordination. Hogan N, Flash T, *Trends in Neurosciences* 10(4):170-174, April 1987.

Controlling Multi-Joint Motor Behavior. Hogan N, Bizzi E, Mussa-Ivaldi FA, Flash T, *Exercise and Sport Sciences Reviews* Vol. 15, 1987.

Coordinating Multi-Joint Motor Behavior. Hogan N, *Proceedings of the ASME 1987 Biomechanics Symposium*, AMD84:383-386, Cincinnati, OH, June 1987.

Quantitative Assessment of the Importance of Elbow Prosthesis Dynamic Behavior in the Performance of Manual Tasks. Hogan N, Miller C, *Proceedings of the RESNA 10th Annual*

Conference, 7:193-195, San Jose, CA, June 1987.

Quantitative Functional Assessment of Control Systems for Upper-Extremity Prostheses. Abul-Haj C, Hogan N, *Proceedings of the RESNA 10th Annual Conference*, 7:284-286, San Jose, CA, June 1987.

An Emulator System for Developing Improved Elbow-Prosthesis Designs. Abul-Haj C, Hogan N, *IEEE Transactions on Biomedical Engineering*, 1987 (in press).

A Microprocessor-Controlled Prosthesis with Extended Physiological Proprioception

Micheal D. O'Riain, Ph.D., P.Eng. and David T. Gibbons, Ph.D., P.Eng.

The Rehabilitation Centre, Ottawa, Ontario, Canada K1H 8M2 and the University of Ottawa, Ottawa, Ontario, Canada K1N 6N5

Sponsor: *The Natural Sciences and Engineering Research Council, Canada; The Royal Ottawa Hospital, and the University of Ottawa*

Purpose—The objective of this project was to assess the effectiveness of Extended Physiological Proprioception (EPP) in positioning the terminal device of our microprocessor-controlled prosthesis. The bench prototype prosthesis was equipped with an electrically powered hand, wrist, and elbow. Shoulder position on the amputated side was used as input.

Progress—Tests have been performed to determine the degree of position proprioception obtained with a single input/output relationship. The results have shown that our system with EPP was significantly

superior to all other systems for controlling the position of the terminal device of an externally powered prosthesis.

Future Plans/Implications—Our system is equipped to handle up to eight different input/output relationships (which we term *linkages*). This is a departure from conventional EPP, but it will increase the usefulness of the prosthesis. However, an as yet undetermined loss in positioning accuracy will result from the use of more than one linkage. A major study is being undertaken of this factor.

Powered Upper Extremity Prosthetics Research and Development Project: Development of a Child-Size Electromechanical Elbow

M. Milner, Ph.D., P.Eng., C.C.E. and R. Galway, M.D., F.R.C.S.(C)

Hugh MacMillan Medical Centre, Toronto, Ontario M4G 1R8

Sponsor: *Variety Club of Ontario, Tent 28*

Purpose—The objective of this study was to develop a miniature child-size electromechanical elbow.

Progress—The initial design requirement was to design a basic mechanical joint without a free swing feature and to provide a unit which could be covered by the prosthetist at fitting. The size of this elbow is to be suitable for children from 3 to 6 years old. The device utilizes the motor/friction drive assembly from the VV812 elbow which is already in production. The final stage of this drive is a worm-and-wheel combination.

Results—Although it is very desirable to cover this unit at fitting, routing the internal wiring proved to be difficult and the need for a passive humeral rotator was identified. As a result, a second prototype will be designed and fabricated to resolve these problems.

Publication Resulting from This Research

A New Variety Village Electromechanical Elbow and Forearm for Juvenile Amputees. Al-Temen I, Mifsud M, Spencer J, Milner M, *Journal of the Association of Children's Prosthetic-Orthotic Clinics* (in press).

Developments in Myoelectric Control Muscle Site Identification for Electrode Placement in Myoelectric Prostheses

Isaac Kurtz (Student), B.Sc.Eng.

Hugh MacMillan Medical Centre, Toronto, Ontario M4G 1R8

Sponsor: *None Listed*

Purpose—It has long been recognized that the success of a prosthetic fitting, in terms of utility to and utilization by the amputee, depends on the quality of the interface between the amputee and the prosthesis. The objective of the muscle site identification project is to improve the quality of the myoelectric prosthetic interface and the efficiency of the provision of myoelectric prostheses through the development and implementation of a new method for identifying optimal muscle sites for electrode placement in myoelectric prostheses.

Progress—Two projects intended to improve the process of muscle site identification have been completed at HMMC in the past few years. The first is a 2-channel data acquisition system which processes the myoelectric signal from two muscles simultaneously and dynamically displays the myoelectric signal activity in digital form. A record of the maximum signal obtained is also displayed to aid the therapist in comparing signals from various muscle sites.

The second project is a 4-channel data acquisition system which processes the signals from four electrodes placed symmetrically about a common reference electrode. There is a digital display of the four signals corresponding to the four electrodes and an analog display indicating to the therapist the direction of increasing signal strength.

The objective of this project is to reduce the

possibility of error in the determination of the "maximal" site by relying on the relative signal strengths of the four channels from a single contraction instead of comparing absolute signal levels from separate contractions. In addition, it is expected that use of this system would save time in the determination of the site of maximal signal activity.

Preliminary Results—The following improvements to the projects described have been proposed: 1) the electrode probe-in compares longitudinally (electrodes 1 and 3) and transversely (2 and 4) derived signals. A new probe which compares longitudinally-derived signals in all directions (1-3, 2-4, 5-6, and 7-8) has been designed; 2) the two data acquisition systems discussed above will be integrated for ease of use in a clinical setting; 3) the software for the muscle site identification will be upgraded. Currently, the display does not respond as quickly as the changing averaged signal. In addition, the current program does not maintain a running average of the incoming signal; 4) the proposed program will calculate the rate of rise of the processed myoelectric signal so that the amputee can be evaluated for eligibility to use a rate-sensitive prosthesis; 5) the program will indicate to the therapist if the level of cross-talk is acceptable for a particular muscle site; and 6) the clinical procedure for utilizing the apparatus will be developed and documented.

II. Orthotics

The Role of Pressure Distribution Measurement in Diabetic Foot Care

Peter R. Cavanagh, Ph.D.; Lee J. Sanders, D.P.M.; David S. Sims, Jr., P.T. M.S.

Pennsylvania State University, University Park, PA 16802 and Veterans Administration Medical Center, Lebanon, PA 17042

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this study was to determine the value of pressure distribution measurement in the prevention of neuropathic plantar ulcerations in the diabetic individual. Based upon a review of the literature and on our own previous work in this area, specific hypotheses tested were as follows: 1) There will be significantly higher pressures under the forefoot and significantly lower pressures under the toes in the diabetic patients, as compared to the control group. 2) The above trends will become more marked over a two-year period. 3) Quantitative assessment of the plantar pressure distribution will be effective in identifying patients who are “at risk” for the development of lesions. 4) The group of patients receiving a program of enhanced foot care will develop significantly fewer non-traumatic plantar lesions than the group receiving normal foot care.

Progress—Phase 1 of the research program was completed. Activities at Penn State University included the completion of a calibration device for the pressure platform, configuration of new computer hardware and development of software for data collection, display and processing. A pool of 100 possible diabetic subjects was identified at the Lebanon VAMC.

Phase 2 was begun with a comprehensive medical screening of 87 diabetic patients and 41 non-diabetic individuals. The examination included detailed measurements of sensation, foot structure and non-invasive vascular tests. Upon completion of the screening process, 60 diabetics were selected for inclusion in the study. The criteria for inclusion were vibratory perception thresholds > 20 units, loss of protective sensation by monofilament testing, history of previous plantar ulceration and structural foot deformities which would predispose the patient

to plantar ulceration. Patients selected were then randomly assigned to two groups—enhanced care and normal care. A third group of 30 subjects was selected from the pool of non-diabetic subjects to serve as age- and weight-matched controls.

Initial pressure data was collected for the control group subjects. Pressure distribution has been measured every 4 months for the normal and enhanced care groups. Three data collection sessions have been completed for each diabetic group with over 2200 trials recorded. The enhanced care group received two pairs of special footwear consisting of extra-depth shoes with soft molded insoles. Patients have attended outpatient clinic visits every 4 to 8 weeks to monitor their progress. An annual patient education conference has been provided to the normal and enhanced care groups. Two of our patients have died, two have had cerebrovascular accidents and two have dropped out of the study for non-medical reasons.

Preliminary Results—A subset of data consisting of 12 subjects from each group ($N = 36$) were selected for the purpose of performing a preliminary analysis. Comparison of peak plantar pressure means between groups showed a significant difference ($p < 0.03$) for non-diabetic controls versus diabetics with a history of ulceration. No significant difference was found between non-ulcer diabetics and diabetics with ulcers, but a clear trend was present, suggesting higher pressures in the ulcer group.

Peak pressure at ulcer locations varied from 312 to 1895 kPa. The highest pressures were noted under the second metatarsal head. In general, the peak plantar pressure corresponded with the site of ulceration but exceptions were noted at the toes and heel.

The incidence of plantar lesions at the beginning

of the study was 8 and 13 for the normal and enhanced care group, respectively. Since the delivery of the special footwear to the enhanced care group there have been only 4 lesions. This represents a 69 percent reduction in the incidence of plantar injuries in this group.

Diabetics with a history of ulceration had significantly greater ($p < 0.005$) deformity as compared to the non-ulcer diabetic group. The most common deformity was found to be clawtoes. Monofilament thresholds were significantly greater in the diabetics with ulceration as compared to non-diabetic con-

trols. No significant difference was found between the two diabetic groups. Mean vibratory thresholds were significantly different ($p < 0.001$) between all three groups. The minimum threshold at the site of ulceration was 13.2 micrometers of displacement.

The vascular index did not vary significantly between groups but some trends were noted. The index tended to decrease in the non-ulcer diabetic group suggesting a mild decrement in blood perfusion. In contrast, the index in the diabetic ulcer group was similar to the non-diabetic controls which may indicate decreased arterial compliance.

Effectiveness of Shock Absorbing Materials in Reducing Heelstrike Forces in Walking

D.D. Moyle, Ph.D.; M. Russo, M.S.; E.W. Berg, M.D.; F. Piehl, M.D.

Bioengineering Alliance of South Carolina, Clemson University, Clemson, SC 29634; William Jennings Bryan Dorn Veterans Administration, Columbia, SC 29203; and University of South Carolina School of Medicine, Columbia, SC 29208

Sponsor: VA Rehabilitation Research and Development Service; Bioengineering Alliance of South Carolina

Purpose—Degenerative changes have been shown to be caused or worsened by mechanical factors, in particular, repetitive loading. Although forces which arise normally in walking are usually absorbed easily by the musculo-skeletal system, this is not necessarily the case in subjects with joint pathology. Forces may cause damage to joints in people whose shock-absorbing capabilities have diminished due to age, trauma, or deformity. It may be possible to replace some of this shock absorbency by using insole materials inserted into the shoes. The effectiveness of several of these materials was the subject of this investigation.

Progress—A heel pad instrumented with eight piezoelectric ceramic discs served as the transducer to measure forces under the feet as subjects walked on a treadmill. The heel pad was placed inside a pair of specially-designed test shoes which all sub-

jects were asked to wear. Subjects walked at a constant, comfortable speed throughout the test. Data was collected, stored and statistically analyzed on a desktop personal computer.

Preliminary Results—Preliminary studies on normal individuals showed that 10 materials out of 23 tested were effective in reducing heel strike forces. Four of these were used in a test on 10 subjects who either had to moderate osteoarthritis or had undergone total joint replacement in the hips or knees. All subjects tested each of the materials and these tests were compared to one with no insole in the shoe. Results showed that all four materials significantly reduced both force and impulse (area under the force-time curve) in all subjects. None of the materials was found to be significantly better than the others in this capacity.

Functional Kinesiology of Knee Bracing

Richard Shiavi, Ph.D.; Thomas Limbird, M.D.; Alvin Strauss, Ph.D.

Veterans Administration Medical Center, Nashville, TN 37203 and Vanderbilt University School of Engineering, Nashville, TN 37235

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—The objective of this project is to investigate the effects of five functional braces on the kinesiology of the injured knee. Measurements will be made using a six-degree-of-freedom goniometry and electromyography during walking and pivoting.

Progress—The first major challenge is to measure the kinematics of the braced knee. A six-degree-of-freedom goniometer has been designed and is being fabricated presently for this purpose. Testing of the goniometer and implementing necessary design changes will be accomplished this year.

Therapeutic Evaluation of the VA San Francisco Therapeutic Molded Shoe and Diabetic Risk Stratification

Richard M. Stess, D.P.M., and Peter M. Graf, D.P.M.

Veterans Administration Medical Center, San Francisco, CA 94121

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—According to Levin, lesions of the foot are responsible for more than one-fifth of the operations performed on diabetic patients. It would therefore be prudent both financially and medically to define the diabetic population at risk and to develop effective methods of intervention such that pedal ulcerations and amputations can be prevented or minimized. The purpose of this project is to: 1) develop and conduct a series of non-invasive examinations which will be used in assessing the predisposition toward foot ulceration and potential lower limb amputation in the diabetic population; 2) develop a tissue breakdown potential index or risk index based on these noninvasive screening examinations; 3) conduct a prospective evaluation of the natural course of diabetic insensate foot; and, 4) conduct a clinical evaluation of the therapeutic effectiveness of the VA San Francisco Therapeutic Molded Shoe.

Progress—The establishment of a multi-disciplinary team was accomplished through the coordination of the STAMP director. A comprehensive history and physical examination was designed specifically for obtaining the most complete information relative to a patient's diabetes, vascular, neurological and biomechanics status. A cross-sectional study of patients in the metabolic endocrine clinic was conducted to determine the frequency of pathological and social

factors presenting to patients with diabetes mellitus.

The VA San Francisco Therapeutic Molded Shoe will be evaluated as to its therapeutic effectiveness. One group of patients determined to be at high risk of ulceration or limb loss will be provided both a molded shoe and sandal. A second similar group of diabetic patients will continue to receive the type of care and shoe gear normally provided to them.

Preliminary Results—A cross-sectional study of the frequency of lower extremity complications secondary to diabetes mellitus of patients presenting to a metabolic-endocrine service has been completed. Analysis thus far has indicated that of 92 patients studied, 52 percent had no neuropathy or foot complication, 32 percent had clinical neuropathy without a history of complication and 16 percent have had a lower extremity complication including pedal ulceration and amputation. Further analysis of the 94-patient study is nearing completion.

There has been established a Diabetic Foot Ulcer Clinic in order to both facilitate and standardize a multi-disciplinary treatment plan. Such a clinic provides the clinical staff the necessary tools to employ the talents of a variety of specialties at one location and at one time. It also provides the team a method to more thoroughly evaluate the efficacy of various treatment plans in a timely fashion.

Future Plans—Prototype molded therapeutic sandals and oxfords have been designed but as yet not evaluated. Both shoe types appear to achieve the goals of lower fabrication time and cost. The therapeutic effectiveness of the shoes will be evaluated

on those high-risk patients being evaluated and treated by the Diabetic Foot Ulcer Clinic. An additional 40 patients with foot ulcers are now being followed in the clinic. Patients from the clinic will soon be recruited into the clinical trials for the shoe.

DataGlove Semi-Automated Hand Function Evaluation System

Samuel Wise, M.D.

Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service (Project #XA458-R)

Purpose—Loss of hand function prohibitively influences the patient, his family and society. Annual costs due to hand impairments total \$10 billion. Improvements in hand and upper extremity function would help the patient become more independent and more socially interactive, thus reducing the burden on the family and society.

The DataGlove will address three major problems in treating hand impairments. These are: 1) assessing the exact extent of the impairment; 2) determining the best therapy for the impairment; and, 3) evaluating the results of therapy, whether from surgery or rehabilitation.

The DataGlove will be used to collect data from patients with impaired function secondary to a number of diseases, including spinal cord injuries, peripheral nerve injuries, and other impairments. After therapy, such as surgical tendon transfers, the hand motions will again be recorded and compared to the motions that were recorded pre-operatively.

The effects of specific transfers and the benefits of one transfer or combination of transfers over another will then be analyzed. Other therapeutic modalities such as hand therapy and external splints will be likewise evaluated. A library of normal hand motions, impaired hand motions, and the effect of different modalities for treating the impairments can then be created.

Thus, the goal will be to analyze "new" data obtained from the DataGlove to determine if it will better guide the choice of therapeutic modalities for specific hand impairments. In addition, it will provide patient education with respect to the hand impairment they have and how it changes with an integrated program of therapy. It will help patients to understand what they can expect from a planned surgical treatment for their own impairment based on the library of previously recorded pre- and post-operative DataGlove analyses.

A Comparison of the Effectiveness of Flexible and Rigid Shoes in Relieving Pain at the Metatarsophalangeal Joints of Rheumatoid Arthritis Patients

Paul Allard, Ph.D., P. Eng.; Hyman Tannenbaum, M.D.; Hubert Labelle, M.D.; Laval Leclerc, M.D.
Pediatric Research Centre, Hospital Sainte-Justine, Montreal, Quebec H3T 1C5, Canada

Sponsor: CAFIR, University of Montreal

Purpose—Rheumatoid arthritis is a systemic inflammatory disease, characterized primarily by joint inflammation, which can lead to permanent joint damage. The foot is involved in up to 88 percent of cases leading to foot pain, ambulation problems, loss of independence and diminished productivity in both the home and work environment. Traditionally, the treatment of foot pain includes rest, med-

ication and the prescription of orthoses. The type of shoes worn can lead to a new load distribution configuration and limit the effectiveness of the orthosis. According to the authors, there is no scientific data examining the role of the shoe material, on the load distribution beneath the metatarsal heads and muscle activation pattern, in the estimation of the performance of the shoe.

Progress—We hypothesized that flexible-sole shoes, which provide cushioning in acute metatarsalgia, can better distribute the load on the metatarsal heads; whereas, rigid-sole shoes, which limit metatarsal motion, will reduce the load acting at the metatarsal heads in chronic metatarsalgia, while still enabling good and efficient foot propulsion. Our study will measure kinematic and kinetic gait parameters (obtained by high speed photography) by placing discrete load cells beneath the metatarsal heads, the lateral border of the foot and the calcaneus: by taking force-plate measurements and by

studying muscle activation patterns in patients with rheumatoid arthritis, whose footwear will be varied from a flexible-sole shoe to a rigid-sole shoe.

The significance of the study will be to obtain a better understanding of the factors which can be controlled in part by the use of different shoe rigidity in the relief of metatarsalgia. Hopefully, measurements will be derived which could have widespread application in determining which patients might benefit best from the purchase of a flexible or rigid shoe.

Neofrakt versus Scotchcast in the Tone Reducing Ankle Foot Orthosis

C. Smith (Student), B.Sc.

Hugh MacMillan Medical Centre, Toronto, Ontario M4G 1R8

Sponsor: Hugh MacMillan Medical Centre Student Research Award

Purpose—This project was designed to test the practicality of an alternative material (Neofrakt) in the design of the Tone Reducing Ankle Foot Orthosis (TRAFO). Present TRAFO design incorporates Scotchcast in the hindfoot and shank portion of the device. Modifications to the orthosis following casting are limited, as Scotchcast does not maintain the property of plasticity once it has cured.

Progress—The Neofrakt casting procedure required the use of padding and cotton stockinette similar to the Scotchcast procedure. All patients were to have undergone a trial fitting in order to allow the orthotist to complete fine modifications and assess pressure areas.

Patient follow-up was to take place at 2-week intervals for a period of 3 months, using forms that would assist in the collection of data which included the examination of the effectiveness and durability

of the Neofrakt material.

Preliminary Results—The casting procedure was assessed to be more difficult with the Neofrakt than with the Scotchcast in all cases. Problems reported in the casting procedure included an excessive material thickness and setting time, poor fit of Neofrakt casting stockinette (resulting in wrinkling on the inner surface of the device), and the leakage of foam through the outer surface of the Neofrakt stockinette. Acceptable limb positioning was obtained in only one of the ten casts taken.

Future Plans/Implications—At the present time, the research team cannot recommend the use of Neofrakt in the TRAFO design. Problems with material properties must be cleared up prior to further involvement of Neofrakt in the casting and construction of the Tone Reducing Ankle Foot Orthosis.

The LSU Reciprocating Gait Orthosis

R. Douglas, C.O. Ph.D. (Hon.), and M. Solomonow, Ph.D.

Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: LSU Department of Orthopaedics

Purpose—The objective of this research was to provide patients suffering lower extremity involvement with an orthotic means to ambulate in a safe

and reciprocal (swinging one leg simultaneously with push off with the contralateral leg) manner.

Progress—A long leg brace evolved and was modified over the last 10 years to meet the objectives of this project. The brace has—with addition to the leg members—pelvic and thoracic supports that allow a substantial increase in balance and stability. The hip joints are engaged to each other with a pair of sleeved Bowden cables so that, during the swing phase of one leg, force is transmitted to the contralateral hip with the cable to induce hip extension, or “push off.” Special locks are available at the hip and knee joints to allow the patient to sit (hip and knee flexion) and stand up in a semi-automatic mode.

Preliminary Results—To date, the brace has been fitted to the following patient categories: cerebral palsy (36); spina bifida (300); muscular dystrophy (60); and paraplegics (225); quadriplegics (36); and, osteogenesis imperfecta (14).

Future Plans—Efforts are being focused on improving the energy transmission efficiency in the hip joint-cable mechanism with the objective of reducing the metabolic energy consumption expended by the patient.

Development of Design Methodology for Anterior Cruciate Ligament-Deficient Knee Braces

M. Solomonow, Ph.D., and R. D'Ambrosia, M.D.

Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: *LSU Department of Orthopaedics*

Purpose—The objective of this project was to develop design methodology of knee braces that will meet the needs of patients with anterior cruciate ligament ruptures or damage.

Progress—A large volume of clinical, physiological and biomechanical data relating to knee performance was evaluated and design criteria developed for the requirements from a knee brace. Evaluation of many commercially available braces demonstrated that

none provided a reliable anterior protection mechanism to prevent tibia subluxation, although varus-valgus protection is available.

Preliminary Results—Two designs were implemented, one of which was also evaluated on a patient. The designs provide anterior tibial protection mechanism or reduction of extension velocity to avoid sudden or fast impact on the joint. Additional patient evaluation is in progress.

Ambulatory Orthoses for the Severely Disabled: A Comparative Study

N. Messenger, B.Sc.; C. Ogilvie, F.R.C.S.; P. Bowker, Ph.D.; D.I. Rowley, F.R.C.S.

Department of Orthopaedic Mechanics, University of Salford, Salford M5 4T, UK and The North Western Orthotic Unit, Hope Hospital, Salford M6 8HD, UK

Sponsor: *The National Fund for Research into Crippling Diseases (Action Research for the Crippled Child)*

Purpose—A great deal of interest is currently being shown, both in the UK and elsewhere, in ambulatory orthoses for the severely locomotor disabled. This has been particularly so in the UK since the recent introduction of the Reciprocating Gait Orthosis (RGO). However, despite the RGO having been available in the USA for a number of years, very little published data is available, and comparative data on alternative devices, particularly the Oswestry Hip Guidance Orthosis, is equally scarce.

In conjunction with a parallel project aimed at determining the physiological benefits of an upright posture and the psychological and sociological effects of various alternative ambulatory orthoses, the aim of this project is to undertake a comparative assessment of four types of orthosis, namely the swivel walker, “full-set” of calipers and the reciprocating devices, the Hip Guidance Orthosis (HGO) and the Reciprocating Gait Orthosis (RGO). A functional assessment of each device, and of the training

of each patient, is to be based on the measurement of the physiological cost of ambulation using a parameter based on heart rate changes, the Physiological Cost Index (PCI), and an analysis of video recordings to obtain the basic temporal distance parameters of the resulting gait. It is also intended to update an ongoing analysis of the total costs to the health service, both of the initial prescription of each device and all subsequent expenditure. Additionally, a procedure for monitoring the long term use of these devices, with a view to assessing their contribution to the everyday lives of their users, is to be initiated.

Progress—A portable heart rate and video monitoring system has been developed to enable PCI and video assessments to be carried out on location.

A large number of patients, principally adult traumatic paraplegics and spina bifida children, have already entered the RGO program. Each is assessed in any current device prior to training, and in their

RGO at 2, 6, and 10 weeks post-final fitting and at regular intervals of 3 to 6 months thereafter, for as long as is practical. A similar procedure is to be adopted with patients entering an HGO program. Additionally, a small group of subjects are to be asked to use each of at least three of the devices, but including both the RGO and HGO, in a randomly assigned serial test, for a period of 3 months each.

Future Plans/Implications—The project is still in its initial stages. It is anticipated, however, that the results will, at the end of our initial period of study in 1991, provide useful information for the professionals routinely involved with the treatment of the severely ambulatory disabled, particularly as regards the prescription criteria for the various devices. In addition, the techniques developed for orthosis assessment will be useful for the routine short- and long-term assessment of patients seen in our orthotic clinics.

The Biomechanics of Flat-Feet Running

Zvi Ladin, Ph.D.; Evan Sherr, B.S.; M. Acierno, B.S.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *NeuroMuscular Research Center*

Purpose—The syndrome of flat-feet (extreme lowering of the arches) is quite prevalent in the human population. If left untreated, it usually causes severe pain in the lower limbs, and may contribute to the incidence of injuries in patients engaged in a physical activity such as running. In-shoe orthoses are usually prescribed to counter the adverse effects of such an anatomical anomaly.

Progress—A clinical study to test the effect of the

orthoses on the biomechanics of running has been undertaken. This study involves having subjects run over a forceplate. The patterns of foot-floor interaction forces, measured by the forceplate, will be studied for flat-feet runners running with and without their orthoses. The study will document the effect of orthoses on the patterns of foot-floor interaction forces, and then compare this information with the patterns produced by normal subjects.

Assistance of Upper Limb Mobility

J.F. Orr, Ph.D.; H. Simpson, B.Sc.; W.V. James, F.R.C.S.

Rehabilitation Engineering Centre, Musgrave Park Hospital, Belfast, Northern Ireland

Sponsor: *The Northern Ireland Prosthetic Orthotic and Aids Service*

Purpose—The aim of this project is to develop a device which supports the weight of the upper limbs of muscular dystrophy patients, allowing residual muscle strength for useful function.

Progress—The former system of overhead supports has progressed from using counterweights and pulleys to suspend the arms, to a design using elastic cords and a lever. The geometry of the design is

such as to provide a constant force throughout the range of movement of a lever from which the arm is suspended. A simple cuff is employed to support the arm, which is so designed to prevent slippage at any position. The device may be fitted readily to wheelchairs, and lifting force can easily be adjusted by an attendant to compensate for varying weights

of clothing. Several prototype units have been assembled for trials, during which final development will take place while seeking a local manufacturer.

Publications Resulting from This Research

Upper Limb Weakness in Children with Duchenne Muscular Dystrophy—A Neglected Problem. James WV and Orr JF, *Prosthetics and Orthotics International* 8:111-113, 1984.

Development of a Powered Orthosis for Lower Limbs

H. Miyamoto; Y. Sakurai; Y. Shimazaki; K. Tokimura

Institute of Biomedical Engineering, Tokyo Women's Medical College, Tokyo 162, Japan

Sponsor: *Office for Life Science Promotion of the Institute of Physical and Chemical Research, Agency of Science and Technology, Japanese Government*

Purpose—To obtain an appropriate gait pattern, a powered orthosis for paralyzed lower limbs is being developed that supports the patient's body and controls lower limb movement. As a final goal, the powered orthosis will enable paraplegic patients to walk on level ground with a variable cadence, to stand and sit, and to go up and down a staircase by appropriate command.

Progress—Considering the results obtained experimentally through the preceding years, a second prototype was designed and constructed in 1986. Its main purpose was to have a powered orthosis for lower limbs of an appropriate size so that control methods explored in the past several years could be tested on paraplegic patients. The orthosis was fabricated in C-FRP (Carbon Fiber Reinforced Plastic) and in thigh and femur parts; four electrohydraulic actuators were incorporated. These actuators now have digital controls, in contrast with the first prototype which used an analog type. Each actuator is controlled by a single-board microcomputer, and all of these are totally controlled by a

microcomputer. Sensory systems such as foot-switch sensors to detect plantar contact, photo encoder to measure relative joint angle, and posture sensor to measure torso inclination in sagittal and frontal planes, are used to accomplish a stable powered walk.

Preliminary Results—By basic experiments on a normal subject, it was verified that this second version of the powered orthosis had sufficient torque for powered walk. The orthosis itself weighs 19.5 kg, and its control wagon 68 kg, which should be moved with the powered walk. A powered orthosis will be realized using these two components.

Future Plans—Since the first orthosis of the second version was successful, a second orthosis for paraplegic patients is under construction. As these two orthoses are identical except for geometrical size, all the control methods will be thoroughly tested on normal subjects prior to the clinical tests. The first clinical results will be obtained by late 1987.

Talus Control Ankle Foot Orthosis: A New Design

Kathleen Byers-Hinkley, M.S., P.T.; Lynne Logan, M.A., P.T.; Robert Brown, C.P.O.

Special Children's Center, Inc., Ithaca, NY 14850

Sponsor: *Special Children's Center, Inc.*

Purpose—This ankle foot orthosis (AFO) was developed jointly by two physical therapists and an orthotist. It provides dorsal support, three points of

control, and normal heel contact with shoe. Plantar surface control, such as arch supports, are not required. It has been used on 28 patients with

neurological and orthopedic needs. The principle guiding this design has been that if the talus can be aligned and held in a normal position, it is the "keystone" of the foot and will provide stability for the rest of the foot.

Progress—An examination procedure to determine if the patient's foot is structurally sound enough to benefit from this type of support has been developed, based on the talus neutral procedure. Gait analysis using high-speed motion picture photography and Vanguard Motion Analysis with several clients with traditional posterior shell AFO's, barefoot, and talus control ankle foot orthoses have shown variable results. We currently hypothesize that one variable is the amount of upper extremity support required for ambulation. It appears that less weight borne on the lower extremities decreases the benefit during gait. X-ray studies were also made to assist the fabricator to achieve better bony alignment.

Preliminary Results—Fabrication of this device requires different procedures for the orthotist. The casting method for creating the positive mold is different. Fitting and trimming this orthosis varies widely from a traditional PSA. Cost will vary with the location and amount of experience of the fabricator. The first few we attempted required several remakes. This design is now the orthosis of choice for providing ankle and foot support in our area.

Future Plans/Implications—We would like to share this design with others in our field. We are currently adding more subjects to our study as well as seeking funding to continue this work.

Publications Resulting from This Research

Talus Control Ankle Foot Orthosis: A New Design. Byers-Hinkley K, Logan L, Brown R, *Orthotics and Prosthetics*, 41(3):22-31, 1987.

Mechanics of Ankle-Foot Orthoses

Narender P. Reddy, Ph.D.; Paul C. Lam, Ph.D.; Mark Yankee, C.O.

Departments of Biomedical Engineering and Mechanical Engineering, University of Akron, Akron, OH 44325; Yankee Bionics, Inc., Akron, OH 44302

Sponsor: *University of Akron*

Purpose—Excess rotations at the ankle-foot complex present a major problem in the comprehensive rehabilitation of certain stroke patients with upper and lower motor lesions. These patients have uncontrolled muscle activity which may develop into the *drop-foot* problem. Abnormal rotations also occur in the case of certain ligament injuries. Ankle-foot orthoses are generally prescribed to mitigate this problem. However, these orthoses have not been evaluated from a biomechanical viewpoint. The purpose of the present investigation is to study the biomechanics of ankle-foot orthoses.

Progress—We have developed two-dimensional finite element models of the ankle-foot-orthosis complex and studied various static and dynamic loading conditions. We compared stress and deformation patterns of the normal foot with those fitted with orthoses. In addition, we experimentally examined the strains developed in the orthosis in a walking cycle. Strain gauges were attached to polypropylene

orthoses. The orthoses were fitted to normal test subjects and the strains were recorded during the gait cycle. The orthosis was held in place with a strap anterior to the calf, and a shoe which held the foot in the lower section. Principal strains were determined from three-element Rosett gauges with assumed values for the material properties.

Preliminary Results—Peak stresses determined from both static and dynamic finite element models were similar in magnitude. Experimental results with strain gauges were consistent with the results of finite element model simulation. Slight geometric modifications of the orthosis were made to eliminate stresses at undesirable points. These design modifications allow functional plantar flexion, reduce instability at the subtalar joint, and facilitate heel-to-toe gait pattern.

Future Plans/Implications—While the present simple two-dimensional analyses demonstrate the feasibility

ity of using finite element models for redesigning the ankle-foot orthoses, further examination of dynamic conditions and more complex three-dimensional dynamic finite element calculations are needed in order to be able to predict the total response of the ankle-foot-orthosis system. Experimental strain analysis could perhaps be done on each orthosis before it is fitted to a patient and should be modified to avoid stresses at undesirable points.

Functional Treatment of Perthes Disease

C. Ogilvie, F.R.C.S.; D.I. Rowley, B.Med.Biol., M.D., F.R.C.S.; T.W.D. Smith, F.R.C.S.

North Western Orthotic Unit, Hope Hospital, Salford M6 8HD, England, and The Children's Hospital, Sheffield, England

Sponsor: None Listed

Purpose—Perthes Disease remains an enigma. While the pathological process of ischemia, revascularization and healing is well known, the initiating insult or agent remains to be identified. The treatment is, therefore, still somewhat empirical, if treatment is thought to be necessary. Some orthopedic surgeons treat by "supervised neglect" with bed rest and possibly traction for pain relief during periods of hip irritability. However, the literature on the subject would suggest that containment of the femoral head within the acetabulum during the active and healing phases, maintains the shape of the head. A normal spherical shape may not be achieved, but a measure of congruent incongruity results between the femoral head and the acetabulum as an acceptable alternative.

Progress—Many orthoses have been produced to maintain the shape of the femoral head. The orthotic devices limit, to a greater or lesser extent, the function of the hip, while maintaining containment by abduction. It was to maintain, as far as possible, the motion of the hip joint, to give a molding effect, that the Trans Pennine Splint (TPS) was designed. This principle is similar to that of the Pavlik Harness used in congenital hip dislocation.

The TPS consists of a polyethylene body jacket, to which the hip abduction flexion hinge is attached. The distal part of this hinge is then attached to a plastic thigh cuff and through a second knee flexion hinge to a calf cuff. These are held in place by elastic strapping with velcro fastening. It is worn throughout the waking hours.

Publications Resulting from This Research

Finite Element Modeling of Ankle-Foot Orthoses. Reddy NP, Pohit G, Lam PC, Grotz RC, *Proceedings of the International Conference on Biomechanics and Clinical Kinesiology of Hand and Foot*, K.M. Patil and H. Srinivasan (Eds.), pp. 97-99, Indian Institute of Technology, Madras, India, 1985.

One More Step in Redesigning the Ankle-Foot Orthosis. Lam PC, Downing M, Reddy NP, *SOMA*, 2(1):36-39, 1987.

The children have full clinical assessment and initial X-rays of the affected hip and a weightbearing radiograph at initial fitting to check containment. Adjustments to the abduction hinge are made as necessary. The orthosis is worn throughout the day. During periods of irritability, bed rest has been advised. Follow-up weightbearing radiographs are taken at 2-month intervals, until healing is adjudged to have taken place, at which time the children are allowed to discard the orthosis.

To date, 22 children (19 boys and 3 girls) have been fitted in Sheffield, and 6 children (4 boys and 2 girls) fitted in Salford. The full range of Catterall Groupings have been treated. The orthoses have proved to be robust and have allowed most of the usual activities of this age group, though organized games and school physical education sessions are not allowed.

Preliminary Results—There have been three children, with four hips involved, who have been allowed to discard the splint. The sphericity of the femoral head assessed by Mose's criteria gave one fair and three good results. Clinically, three hips had full range of movement; one had limitation of rotation in extension. The tolerance of the orthosis by the children has been remarkable, we believe, due to the amount of activity it allows.

Future Plans/Implications—Within the next few months, we hope to have more children able to discard the orthosis. However, the true results can only be assessed many years from now, and it is the hope of the authors that this will prove possible.

III. Total Joint Replacement and Other Orthopedic Implants

A. General

Absorbable Fixation Devices: Orthopaedic and Reconstructive Surgery (Pilot Study) _____

Edward Berg, M.D., and F.W. Cooke, Ph.D.

William Jennings Bryan Dorn Veterans Hospital, Columbia, SC 29201

Sponsor: VA Rehabilitation Research and Development Service (Pilot Proposal #A940-PA)

Purpose—The goal of this pilot study is to demonstrate that recent advances in polymer sciences, glass science, composite fabrication and biomechanics can be synthesized into a process for the manufacture of functional absorbable fixation devices. In addition, the effectiveness of the devices for the stabilization of osteotomies will be demonstrated in animal studies.

Absorbable fixation devices could replace a large portion of the metal devices which are now in use and which must often be removed for cause (e.g., stress shielding osteopenia, late infection, etc.). The absorbable device would dissolve slowly after healing of the lesions thus obviating the removal operation. The material for the implant will be a composite consisting of a polylactic acid (PLA) polymer

matrix stiffened with 15 μm fibers of a phosphate glass called Metaglass (metabolizable glass). The Metaglass has better stiffness and dissolution behavior than the Ca metaphosphate glasses used by previous investigators.

In this study, the fibers will be produced in Kg quantities and be combined with the PLA to yield composite intramedullary rods. The strength of the rods will be determined by mechanical testing and their ability to stabilize femoral osteotomies in cats will be evaluated. If this pilot study is successful, it will be followed by a request for a full scale, type I study to optimize the fabrication process, complete characterization of the materials and devices and assess long-term *in vivo* effects.

Determination of the Effects of Implant Interface Mechanics on Bone Remodeling _____

G.V.B. Cochran, M.D., M.Sc.D., and J. Brunski, Ph.D.

Helen Hayes Hospital, West Haverstraw, NY 10993; Rensselaer Polytechnic Institute, Troy, NY 12181; and Surgical Research Service, VA Medical Center, Castle Point, NY 12511

Sponsor: VA Rehabilitation Research and Development Service; New York State Department of Health

Purpose—The relationship between bone remodeling and mechanical stresses in bone has vital implications with respect to the interaction between orthopaedic implants and bone, especially with regard to loosening of joint replacement prostheses. The objective of this study is to gain knowledge of the morphological and physiological reactions of bone in relation to mechanical stress at the interface between bone and an orthopaedic implant.

Progress—Our research is attacking the problem by means of special titanium screw implants in canine bone. Three months following the insertion of the screws, they are subjected to a programmed loading regimen by an external device. Stresses at the interface and within adjacent bone are calculated by finite-element analysis, while the bone reactions are determined by quantitative histology and compared with local stresses. Because successful joint

replacements are dependent on secure and permanent fixation in bone, this study represents an unusual attempt to improve implant design by examining the effect of local stresses and micromotion on interfacial bone.

Preliminary Results—In the prior phase of this project, we demonstrated that the state of bonding or adherence between bone and the implant is a major factor in the stress patterns produced. At present, for physiological applications, mechanical bonding must be considered as not present. Under special circumstances, there may be direct bonding or "osseointegration" between smooth titanium and bone surfaces but further research on this possibility is required. In addition, we developed techniques applying programmed loading to the bone-implant interface and assessing results. These techniques were tested on a series of special screw implants in canine radius and mandible. Under the loading regime employed (50-110N at 1/2Hz for 500 cycles/day over 5-7 days), we found direct bone opposition to titanium surfaces in the range of 37-72 percent. Furthermore, evidence of elevated fluorochrome labels in the interfacial region was clear, but no significant differences were noted between loaded and nonloaded implants on a group basis under the regime tested. At present, loading techniques are being tested further and calibrated for a sequential series of implant loadings.

Future Plans/Implications—Three types of test are planned for the grant period. In one, the same special screw implants in canine tibia will be loaded in a manner similar to the experiment already completed but under a different regime, including higher loads and allowing a greater period for remodeling

events to take place prior to sacrifice. In a second experiment, direct bone bonding (osseointegration) will be examined in relation to smooth (press fit) titanium implants in canine tibia. In the third series of tests, a similar experiment will be done but selected implants will be subjected to loading to cause micro-motion at the interface.

Publications Resulting from This Research

- Finite Element Models of Implants in Bone: Interfacial Assumptions.** Hipp JA, Brunski JB, Cochran GVB, Shephard MS, in *Biomechanics: Current Interdisciplinary Research* (S.M. Perren and E. Schneider, Eds.), 447-452, Martinus Nijhoff Publishers, Dordrecht, 1983.
- Modeling the Bone-Implant Interface in a Study of Interfacial Bone Adaptation/Damage.** Brunski JB, Hipp JA, Shephard M, Cochran GVB, *Advances in Bioengineering* (N. Langrana, Ed.), 43-44, 1985.
- Biomechanics and Histomorphometry of the Bone-Dental Implant Interface.** Hipp JA, Brunski JB, and Higuchi KW, Second Annual Symposium of the American Academy of the Implant Dentistry Research Foundation, 1986, *Journal of Oral Implantology*, 1987, (in press).
- Method for Histological Preparation of Bone Sections Containing Titanium Implants.** Hipp JA, Brunski JB, Cochran GVB, *Stain Technique*, 1987, (in press).
- Investigation of 'Osseointegration' by Histomorphometric Analyses of Fixture-Bone Interfaces.** Hipp JA, Brunski JB, Cochran GVB and Higuchi KW, *Journal of Dental Research* 66:186, 1987 AADR Meeting, Chicago, IL, March 1987.
- Histomorphometry of 'Osseointegrated'-Type Interfaces Subjected to Different In Vivo Loading Protocols.** Hipp JA, Brunski JB, Cochran GVB, *Proceedings of the 13th Annual Meeting of the Society for Biomaterials*, 48, June 2-6, 1987, New York.
- Structural Characterization of Bone-Titanium Interfaces of 'Osseointegrated' Dental Implants.** Hipp JA, Brunski JB, Cochran GVB, Higuchi KW, Dempster D, Meenaghan MA, *Journal of Biomedical Material Research*, (in preparation).
- Reaction of Bone-Titanium Interfaces Subjected to Different In Vivo Loading Histories.** Hipp JA, Brunski JB, Cochran GVB, Higuchi KW, Dempster D, Meenaghan MA, *Journal of Orthopedic Research*, (in preparation).

Implant Fixation by Postinsertion Pressurization of Polymethylmethacrylate

F. Richard Convery, M.D. and Savio L-Y Woo, Ph.D.

Veterans Administration Medical Center, San Diego, CA 92161 and UCSD Medical Center, San Diego, CA 92103

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The problems associated with failure of the bone-cement interface after total joint replacement are well documented. Early studies in our laboratory have shown increasing strength of this interface with sustained pressurization of PMMA

up to 80 psi.

An *in vitro* study has just been concluded comparing sustained pressurization of PMMA at 100 psi to a regulated handpacking technique that simulates what is currently being performed clinically. The

objective was to study the biomechanical characteristics of the bone-cement interface using the canine knee model. After subchondral osteotomy, the canal was reamed, brushed, lavaged, and a cement plug was placed. One side was pressurized at 100 psi using a cannulated prosthesis designed in this laboratory, and the contralateral side was hand-packed. Specimens were sliced into eight 5-mm sections, which were then loaded and tested to failure at a deformation rate of 0.1 cm/min. Results showed that apparent strength and stiffness of the interface were 20-40 percent higher for the 100 psi side than for the handpacked side.

Progress—Based on the above results, we are beginning the long-term *in vivo* phase of our project. A number of modifications have been made to our constrained total knee prosthesis. The efficacy of this model has been shown in our last canine which was ambulatory with full weightbearing for 4 months following a unilateral TKR. Under general anesthesia, a TKR will be performed on one hind leg. The side and the technique (either sustained high pressure or hand packing) will be randomly assigned. The animals will be followed radiographically and will be sacrificed on a schedule of 4, 8, or 12 months. The bones will be retrieved, sliced into eight 5mm sections, and either tested to failure or used for histology.

Retired racing greyhounds will be the animal of choice, although mongrel dogs may be required. (A study is under way to look at variation of bone between greyhounds and mongrels. We are examining bone quality and density using the Hologic Excaliber Radiographic Imager, the calcium-ash percentage, and biomechanical properties of the bone.)

A study that will be completed in August 1987 is examining *in vivo* time zero canines versus *in vitro* canine knees. This study is assessing differences in

penetration and biomechanical characteristics of the bone-cement interface under surgical conditions where a bone-blood barrier affects cement penetration.

Another study in the lab involves the measurement of plug migration during sustained pressurization. Four different types of plugs are used: bone, PMMA, and 2 commercial silastic plugs. Human cadaver femurs are harvested, reamed, lavaged, plugs are sized, and inserted. The bones are then pressurized at a sustained 100 psi. Plug migration is measured radiographically.

Several other projects have been completed over the last year. These include two studies done in conjunction with the Department of Radiology. The first involved a correlation of various scanning techniques (QCT, DPA) with compressive strength in human cadaver spinal bodies. The second involved scanning human cadaver femoral necks using the same techniques and the subsequent fracturing of the necks to measure biomechanical characteristics.

As deep venous thrombosis continues to be a major concern in total joint surgery, another study looked at the effects of Sodium Warfarin, a highly used anticoagulant and Vitamin K antagonist that interferes with the actions of Osteocalcin (BGH), which is probably involved in the calcification of bone. Porous-coated devices were implanted into the distal ends of rabbit femurs. The rabbits were then placed on a regime of Sodium Warfarin, IM, until they were sacrificed at 3 and 6 weeks. The implants were then pushed out on a universal testing apparatus to determine whether the Warfarin had affected the bone ingrowth. Histology and serum BGH levels are still to be completed. A similar completed study examined three-point bending on bones from rats kept on a Warfarin regime.

A list of abstracts of presentations and publications is available from the authors.

The Effect of Surgical Fit on the Biological and Mechanical Response to Porous Surfaced Implants

Stephen D. Cook, M.D.

Veterans Administration Medical Center, New Orleans, LA 70146 and Tulane University School of Medicine, Department of Orthopaedics, New Orleans, LA 70118

Sponsor: VA Rehabilitation Research and Development Service (Project #XA136-3RZ)

Purpose—Ideally, a porous surfaced implant relying on bone ingrowth fixation should make initial ap-

position with the surrounding bone. Unfortunately, this is not always achieved surgically at all locations

and a space between the implant and bone is present. This space may be the result of deficiencies in instrumentation design, implant design or surgical technique. The gap may severely alter the type, amount, and rate at which tissue infiltrates the porous implant surface. Thus, the achievement of significant fixation strength may be delayed or ultimate attachment strength affected. A model to study the effect of such gaps on the quantity and quality of bone growth into a porous surfaced implants in both the cancellous and cortical bone regions has been developed and will be used to study these parameters including the interface attachment strength.

Implants will be constructed by threading varying diameter porous coated titanium alloy discs on a central rod. The implants will be surgically placed bilaterally in the femoral intramedullary canals of 25 adult dogs. Uniform gap spaces of 0.0, 0.25, 0.5, 1.0, and 2.0 mm in width will be produced in both the cancellous and cortical bone regions of each femur. At intervals of 4, 8, 12, 24, and 52 weeks postoperatively, 5 animals will be sacrificed and

implant specimens will be mechanically tested to determine interface shear stiffness and strength of attachment. All specimens will be tested on a MTS closed-loop hydraulic system using a ramp type load below interface failure to first determine the interface shear stiffness. Subsequent loading to interface failure will then determine the ultimate strength. Intact specimens as well as those mechanically tested, will then be processed using undecalcified techniques to produce histological and microradiographic sections for microscopic evaluation. The amount of bone growth within the porous surface as well as the amount of bone filling the gaps will be quantified on all specimens using a computer aided microscopic image analysis system. The study will yield differences in the biological and mechanical characteristics between varying gap spaces in both the cortical and cancellous regions as a function of time. Differences in the tissue ingrowth characteristics in the lateral, medial, anterior, and posterior locations in the cortical and cancellous regions will also be determined.

The Mechanical Properties of Porous-Coated Orthopaedic Alloy

Stephen D. Cook, Ph.D.

Veterans Administration Medical Center, Rehabilitation Research and Development Center,
New Orleans, LA 70146

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Numerous studies have shown that porous titanium and Ti-6Al-4V alloy systems provide a biocompatible interface between substrate and bone, resulting in firm implant fixation and potential long-term retention. In order to achieve an acceptable pore size for bone ingrowth, Ti-6Al-4V alloy systems often must be heat-treated above the beta transus (992° C). This transforms the as-received, equiaxed microstructure, recommended for surgical implants, to a lamellar alpha-beta distribution which has been shown to demonstrate the worst fatigue properties of the most common structures attainable in Ti-6Al-4V alloy. However, post-sintering heat treatments may be used to produce microstructures more resistant to crack initiation and propagation than the lamellar microstructure. The objective of this study was to investigate the influence of microstructural variations on the fatigue properties of uncoated and

porous-coated Ti-6Al-4V alloy material through the use of post-sintering heat treatments.

Progress—Uncoated and porous-coated Ti-6Al-4V alloy fatigue specimens were subjected to a sintering heat treatment to produce a lamellar microstructure. In addition, two post-sintering heat treatments were used to produce coarse and fine acicular microstructures in uncoated and porous-coated specimens. The heat treatments were as follows: 1) lamellar: 2 hr. soak at 1300° C; slow cool; 2) coarse acicular: 2 hr. soak at 1300° C; slow cool through the beta transus; Argon quench; 4 hr. anneal (low in the alpha-beta region); Argon quench; 3) fine acicular: 2 hr. soak at 1300° C; Argon quench; 4 hr. anneal (just below the beta transus); Argon quench.

Rotating beam (reversed bending) fatigue testing was performed on the specimens using an R.R.

Moore High Speed Fatigue Testing Machine. All specimens were tested to 10^7 cycles or to failure, whichever occurred first. As-received, equiaxed specimens were tested to provide a reference strength for the microstructures examined, as well as to study the effect of porous coating. The strengths for the porous-coated specimens were calculated using the original substrate diameter. Statistical analysis was performed, using the Probit method by obtaining sets of tests at the same stress level performed above and below an endurance limit. The percentage of specimens which survived 10^7 cycles was plotted on probability paper versus the stress at which the samples were tested. A regression line was determined through these survival data points, and the stress at which the probability of survival was 50 percent was obtained from this line. This value was defined as the endurance limit.

The lamellar microstructure obtained from the sintering heat treatment consisted of platelike alpha in a retained beta matrix. The acicular microstructures contained alpha grain spikes in a beta matrix, with the fine acicular structure consisting of smaller alpha needles and less beta.

Results—As expected, the as-received specimens exhibited the best fatigue properties. For the uncoated heat-treated specimens, the lamellar speci-

mens displayed the lowest endurance limit value, while the acicular specimens displayed the highest endurance limits and differed only slightly. The endurance limit for the fine acicular specimens showed a marked 25.4 percent increase over the lamellar specimens.

For the porous-coated specimens, stress concentration sites were introduced at the sintered areas of contact between powder particles and substrate. This notch effect caused a significant decrease in endurance limit, particularly for the lamellar specimens. Again, the acicular specimens exhibited endurance limits which differed very slightly. The endurance limit for the fine acicular specimens displayed a 15.7 percent increase over the lamellar specimens.

Future Plans/Implications—This investigation revealed that the fatigue properties of Ti-6Al-4V alloy improved as alpha grain size decreased in the heat-treated material. Reduction in the alpha grain size resulted in minimization of the mean free slip path for crack initiation and propagation. Therefore, while a porous structure strongly affects fatigue behavior, the strength of the substrate, often left uncoated on the lateral (tensile) aspect of femoral hip components, can be significantly improved by reducing alpha grain size.

Retrieval and Analysis of Orthopaedic Implants

Stephen D. Cook, Ph.D.; Kevin A. Thomas, Ph.D.; Ray J. Haddad, Jr., M.D.
Veterans Administration Medical Center, Rehabilitation Research and Development Center,
New Orleans, LA 70146

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Extensive research over the past two decades has led to the development and sale of porous-coated joint replacements for humans, relying on fixation without the use of PMMA bone cement. Short-term clinical results have been essentially equivalent for non-cemented porous-coated hip and knee implants. When compared to simultaneous experiences with cemented devices, histologic evaluations of retrieved porous-coated hip devices have been reported and demonstrated that bone growth did occur, in some cases, while not occurring in other series. This study performed a detailed histologic and microradiographic evaluation of tissue growth into 80 retrieved human nonce-

mented porous coated hip and knee components removed from 53 patients.

Progress—The retrieved devices studied included 52 total knee components retrieved from 30 patients, and 28 total hip components retrieved from 23 patients.

The total knee specimens included components from: the Howmedica, Inc. PCA Primary Knee (12 patients, 3 femoral, 7 tibial, and 8 patellar components, average patient age 68 years, average time *in situ* 13 months); the Richards Medical Company Tricon-M knee (3 patients, 3 femoral, 2 tibial, and 2 patellar components, average patient age 63 years,

average time *in situ* 4 months); the Dow Corning Wright Whiteside Knee (11 patients, 9 femoral, 10 tibial, and 3 patellar components, average patient age 65 years, average time *in situ* 13 months); and the DePuy New Jersey LCS and Synatomic Knees (4 patients, 1 femoral, 1 tibial, and 3 patellar components, average patient age 52 years, average time *in situ* 3 months).

The total hip components included specimens from: the Howmedica, Inc. PCA Hip (13 patients, 6 femoral stems, and 8 acetabular cups, average patient age 53 years, average time *in situ* 7 months); the DePuy AML Hip (7 patients, 5 femoral stems, and 4 acetabular cups, average patient age 49 years, average time *in situ* 15 months); and the Zimmer Harris-Galante Hip (3 patients, 3 femoral stems, and 1 acetabular cup, average patient age 50 years, time *in situ* 8 months); and the Implant Technology LSF Hip System (1 patient, 1 femoral stem, patient age 52 years, time *in situ* 1 month).

All retrieved components were inserted without the use of bone cement and in no case was the retrieved component removed due to clinically apparent loosening. Six knee components and one femoral stem were recovered post mortem or following amputation. The remaining 65 components were obtained following a revision surgical procedure.

The removed components, along with any adhering tissue, were immediately fixed in a 10 percent buffered formalin solution, followed by dehydration in graduated ethyl alcohol and embedded in methylmethacrylate. Undecalcified histologic and corresponding microradiographic sections were then produced, with the implants in place, using diamond cutting and grinding techniques. Serial sections were cut from regions of interest with a high speed diamond saw and mounted onto acrylic slides. The sections were first ground to 100-microns thickness using a precision swivel head grinder and microradiographs were produced. The sections were further ground to 50-microns thickness and stained with toluidine blue and basic fuchsin. The sections were then qualitatively examined in transmitted and polarized light for type, degree, and distribution of tissue ingrowth.

Results—The histologic sections revealed varying amounts of bone growth into the porous coating, with no component having more than 10 percent of

the available porous material ingrown with bone in any case. No bone ingrowth was observed in approximately one third of all the components, while in one third less than 2 percent of the available porous surface had bone ingrowth. The remaining one third of the components had between 2 and 10 percent of their porous surface containing bone. In all cases, a dense connective tissue layer separated the majority of the implant surface from the underlying bone, which often displayed marked resorption. The fibrous tissue layer varied in thickness up to approximately 2 mm; this layer was in general acellular and was of an encapsulating nature in components with little or no bone ingrowth. In components with greater bone ingrowth, the fibrous tissue orientation observed in polarized light indicated a radial orientation from the implant surface indicative of some load-transmitting ability. Fibrous tissue which contained macrophages and multinucleated foreign body giant cells, was found within the porous structure in a limited number of samples. This occurred primarily in implants with no bone ingrowth. In the knee components, bone ingrowth was found to occur only in isolated areas, most commonly around the fixation pegs on the femoral and tibial components, while rarely occurring under the tibial tray portion. However, no difference in either the incidence or amount of bone ingrowth was observed between the different components (i.e., tibial, femoral or patellar) or the different manufacturers.

Analyses of the histologic sections from the total hip components revealed similar results to knee components with respect to the incidence of bone ingrowth. Approximately one third of all hip components had no bone ingrowth, one third had less than 2 percent bone ingrowth, and one third had 2-10 percent of their available porous surface ingrown with bone. In general, greater bone ingrowth was observed in the femoral stems with little or no bone ingrowth found in the acetabular components. The exception was the Zimmer Harris/Galante cup which had approximately 8 percent of its surface ingrown with bone. This component uses adjunct screw fixation for initial stability. the greatest bone ingrowth observed in the femoral components was at the distal tip of a fully porous-coated DePuy AML femoral stem. Femoral components, in general, had the greatest bone ingrowth at the distal portion of their porous coating. The type and amount of tissue

ingrowth varied extensively among different sections from any device, and even within a single section, although most femoral stems had some medial bone ingrowth. The bone at the fibrous tissue interface often showed marked resorption with numerous areas of osteoclastic activity. This was similar to that observed in the knee components. With time, further bone resorption and an increase in fibrous layer thickness might be expected in a number of these cases. There were no vast differences in ingrowth characteristics among the different porous coating implant designs.

Future Plans/Implications—The goal of total joint replacement is the long-term restoration of pain-free function. It is evident from the results of these retrievals that extensive bone ingrowth will most likely not occur in any component; yet it appears

that the combination of limited bone and fibrous tissue ingrowth is adequate for implant fixation, providing an effective means of stress transfer. The long term success of this type of biological fixation remains unknown.

The limitations of implant retrieval studies of this type are many, including limited information concerning the size and nature of the subject population, incomplete patient histories, and unknown reasons for implant removal. A significant number of post-mortem specimens would obviously be desirable, since the majority of the specimens in the study were removed at revision surgery, often due to poor implant position. However, in spite of limitations, the analyses of retrieved specimens represents the best means for evaluating biological ingrowth systems and provides a mechanism for evaluating and assessing their long-term potential.

A Model to Study the Mechanical Behavior of Osteoporotic Bone

Stephen D. Cook, Ph.D.; Kevin A. Thomas, Ph.D.; Mark A. Kester

Veterans Administration Medical Center, Rehabilitation Research and Development Center,
New Orleans, LA 70146

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The loss of bone mass, and consequently, bone strength, in persons aged forty and beyond is a continuing problem to the orthopaedic community. This progressive loss has been documented by radiographs, autopsy materials, CAT scans, and single or dual photon absorptiometry. Orthopaedic problems arising from osteoporosis include fractures of the lumbar spine, distal radius, and the femoral neck. Likewise, this age group represents the fraction of the population that will require prosthetic replacement of a joint. Unfortunately, little information is available concerning the mechanical properties of osteoporotic bones and its interaction with prosthetic devices.

Nutritional secondary hyperparathyroidism (NSH) provides an excellent mode for studying the behavior of osteoporotic bone. NSH is a generalized metabolic bone disease characterized by osteopenia which may be induced by a diet which is either too low in calcium and/or too high in phosphorus. Krook *et al.* used such a diet in small laboratory animals and determined that early hypocalcemia was produced by low dietary calcium alone which induced hyper-

parathyroidism. Henrikson also reported that dietary hyperparathyroidism induced by feeding small laboratory animals a diet of 0.12 percent calcium and 1.2 percent phosphorous resulted in generalized skeletal lesions which were more accentuated in the jaws. Cook *et al.*, using the diet of Henrikson, reported the development of an osteoporotic condition produced by NSH as histologic, histomorphometric and biochemical analysis. They reported that *in situ* mechanical testing indicated significant differences in the strain state for NSH and control diet animal femora. Further, the *in vitro* introduction of a Co-Cr-Mo alloy femoral head prosthesis was reported to significantly alter the stress state in the control and NSH femurs. However, this study was limited to a duration of 20 weeks and no mechanical or histologic data was obtained concerning the *in vivo* response to a prosthetic device. The objective of the current study was to investigate the long term consequences of NSH-induced osteopenia. Also the effects of porous hip endoplasty implanted *in vitro* and *in vivo* were investigated.

Progress—The study involved 22 skeletally mature, colony-reared female beagles with an average age of 18 months. Twelve of the animals were placed on a low calcium/high phosphorus (experimental) diet. Ten of the animals were placed on control diets. After six weeks on their respective diets, the “control” and “experimental” animals were implanted with a porous coated hip endoprosthesis with or without bone cement. The animals were followed radiographically and blood chemistries were taken bimonthly. Parathyroid hormone (PTH) levels were determined, as were serum calcium and phosphorus levels. Soft and hard tissue biopsies were evaluated. Mechanical testing involved placement of five uniaxial strain gauges (3 medial and 2 lateral) on the femurs under fluoroscopic control to assure uniform gauge placement relative to the porous device. The most proximal medial and lateral gauges were placed at the level at which the porous coating ended. Distally medial and lateral gauges were positioned at the device tip. A final medial gauge was located one centimeter distal to the device tip. Gauges were placed at corresponding locations along both femurs and then loaded in a specially designed test fixture to 100 lbs. This loading was applied for five cycles with the specimen kept wet with saline. Following testing, the unoperated limb was prepared for hemiarthroplasty. A Richards Canine II Co-Cr-Mo alloy femoral hip prosthesis (small) was then cemented into place using polymethyl methacrylate. These femurs were then reloaded using the identical protocol as for the intact and operated femurs.

Preliminary Results—Analysis of blood chemistry

levels indicated statistically significant differences between the PTH levels of the “control” and “experimental” animals. At two weeks post-diet initiation, the animals having been fed the low calcium/high phosphorus diet exhibited significantly higher PTH levels throughout the entire duration of the study. There were no differences observed between the serum phosphorus levels of the two groups. Serum calcium levels tended to decrease over time for the experimental animals, although those values were not observed to be significantly lower at each chemistry test interval. It is thus assumed from the blood test results that hyperparathyroidism resulted in the experimental animals secondary to calcium deficient diet induction.

The results of the mechanical testing indicated that there was no significant difference between the control and experimental unoperated femurs at the three-month time period. At the 4.5-month period the strains were higher in the low calcium diet animals. The strains in the 6-month animals were approximately the same as the 4.5-month animals for the unoperated limbs. Subsequent to *in vitro* device implantation, the strains in the femurs generally increased. This increase may be in part due to the stress rising effect of the tip of the device and the end of the porous coating. Histologically, the region between the most proximal and distal medial gauge location in the retrieved operated, femur was typically an area of bony hypertrophy. Generally, the strains were lower in the devices which had been inserted with bone cement when compared to those relying solely on the porous coating for fixation.

Ferrographic and Biochemical Analysis of Wear Particles in Human Joints

D.C. Mears, B.M., B.Ch., Ph.D. and C.H. Evans, Ph.D.

Orthopaedic Research Laboratory, University of Pittsburgh School of Medicine, Pittsburgh, PA 15261 and Veterans Administration Medical Center, Pittsburgh, PA 15240

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This project aims to investigate wear particles within human synovial fluid, both as diagnostic indicators and as participants in intra-articular pathophysiological changes.

Progress—Ferrography is being used for the former purpose, while the latter aspect is being addressed

through the use of biochemical, cellular, and animal studies.

Results—Our results clearly show that the wear particles contain valuable diagnostic information, and that ferrography can be used to obtain this information. The biochemical studies have provided

good evidence for an involvement of wear particles in the pathophysiology of arthritis. We are presently investigating the molecular mechanisms through which wear particles modulate synovial metabolism. In particular, a cDNA probe to the collagenase mRNA is being employed to help investigate the way in which the particles promote the synthesis of collagenase.

Also under evaluation is the possibility that mechanisms, analogous to those we have identified as contributing to arthritic degeneration, may also be involved in the loosening of prosthetic joint replacements.

Publications Resulting from This Research

Studies on the Stimulation of the Bacterial, Collagenolytic Enzyme Clostridiopeptidase A by Cobalt (II) Ions. Evans CH, Mason GC, *Int. J. Biochem.* 18:89-92, 1986.

The Role of Implant Materials in Promoting the Aseptic Loosening of Prosthetic Devices. Ferguson GM, Evans GH, *Interactions of Cells with Native and Foreign Surfaces*, N. Crawford and D.E.M. Taylor (Eds.), Plenum Press, New

York, NY, pp. 279-286, 1986.

Demonstration of the Principle of Paramagnetic Chromatography for Resolving Mixtures of Particles. Evans CH, Russell AP, Westcott VC, *J. Chromatog.* 351:409-415, 1986.

Chondrocyte Activation in Response to Factor(s) Produced by a Continuous Line of Lapine Synovial Fibroblasts. Watanabe S, Georgescu HI, Mendelow D, Evans CH, *Exp. Cell Res.* 167:218-226, 1986.

Modulation of Chondrocyte Metabolism by Cytokines Produced by a Synovial Cell Line. Evans CH, Georgescu HI, Mendelow D, Sung K, Tsao M, Watanabe S, *Development and Diseases of Cartilage and Bone Matrix*, A. Sen and T. Thornhill (Eds.), Alan Liss Inc., New York, NY, pp. 319-329, 1987.

Measurement of the Susceptibility of Paramagnetically Labelled Cells with Paramagnetic Solutions. Russell AP, Evans CH, Westcott VC, *Anal. Biochem.* 164:181-189, 1987.

The Synovial Production of Collagenase and Chondrocyte Activating Factors in Response to Cobalt. Ferguson GM, Watanabe S, Georgescu HI, Evans CH, *J. Orthop Res.* (In press).

Articular Responses to Purified Cartilage Proteoglycans. Boniface RJ, Cain PR, Evans CH, *Arthritis Rheum.* (In press).

Increased Levels of Collagenase mRNA in Chondrocytes Exposed to Synovial Factors. Lin CW, Phillips SL, Brinckerhoff CE, Georgescu HI, Evans CH, *Trans. Ortho. Res. Soc.* (In press).

B. Hip

Design Stress Analysis of Porous Ingrowth Hip Replacements

Dennis R. Carter, Ph.D.; Dave Fyhrie, Ph.D.; David Schurman, M.D.; Rob Wood, M.S.; Tracy Orr, M.S.
Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objective of this study is to develop design concepts for porous ingrowth total hip replacements based upon a knowledge of the stress fields in the hip before and after joint arthroplasty. In analyzing and interpreting results, attention will be paid to 1) consistency between the calculated stress fields and bone trabecular morphology, 2) contact areas at the joint and implant interfaces, 3) initial stability of the implants under various loading conditions, 4) the types of stresses created at the porous ingrowth surfaces, and most importantly, 5) the manner in which bone may remodel in response to the change in bone stress caused by the implant.

Progress—Anatomical specimens were sectioned, X-rayed, and photographed to document geometry, distribution of bone density, and trabecular orientations. From these sections, 2-D finite element

models of the acetabulum and femur were generated. Similar models with various porous implant components were also constructed. We have developed a remodeling theory using a multi-load stress history approach which predicts the distribution of bone density in the natural and prosthetic femur. The technique is an iterative approach in which the bone is initially a solid, homogeneous structure with a constant bone density. The results are compared with normal bone anatomy and with findings from clinical studies.

Results—Our finite element results of the acetabular region have provided new insights into how stresses are transmitted from the head of the femur to the pelvis. By simulating the implantation of an acetabular cup component, we were able to reconfirm some of the design principles that have been evolving

concerning metal backing of this component. The application of our iterative bone remodeling theory has proven to be a major benefit in trying to establish how the bone may redistribute itself after implantation of the prosthesis. Using this theory, we find that we can recreate, on the computer, the natural bone morphology of the proximal femur. Starting with a solid block of bone, the remodeling routine predicted the development of a diaphyseal cortex and the dense compressive trabecular column through the head. The dense trabecular bone corresponding to the arcuate system in the lateral superior neck was also formed.

Application of our remodeling techniques to porous ingrowth components has confirmed some of the experimental results that have been reported by others. Our computer examinations of the surface replacement component with the central peg has predicted bone remodeling that is characterized by a dense deposition of bone around the peg. Our remodeling technique has also indicated that our recently developed epiphyseal replacement prosthesis may be very well designed to avoid adverse remodeling influences after implantation. We have made prototype implants with this new design and are planning some experimental implantations.

Effects of Treatments for Heterotopic Bone Formation on Biological Fixation

Stephen D. Cook, Ph.D.

Veterans Administration Medical Center, Rehabilitation Research and Development Center,
New Orleans, LA 70146

Sponsor: VA Rehabilitation Research and Development Service (Project #XA450-R)

Purpose—Ectopic ossification following total hip arthroplasty is a frequently reported complication, with occurrences ranging from 1 to 62 percent. The basic process of this phenomenon involves the laying down of osteoid matrix by osteogenic-competent mesenchymal cells. This is followed by crystal deposition and ultimate mineralization of the matrix. Considerable research has manifested controversial results regarding treatment modalities for the prevention of heterotopic bone formation. Recommendations for its prevention include the use of diphosphonates, indomethacin and radiation therapy.

Diphosphonates have been shown to inhibit growth of hydroxyapatite crystals *in vitro* and have been thought to prevent pathological calcification *in vivo*.

Future Plans—We intend to further develop our remodeling theory and improve the computer codes which implement this theory. More extensive examinations of bone remodeling around prosthetic components will be conducted in two-dimensional as well as three-dimensional analyses. We are proceeding with the manufacture of epiphyseal replacement prosthetic components based on some of the results of our analyses.

Publications Resulting from This Research

Contact Finite Element Stress Analysis of the Hip Joint. Rappaport DJ, Carter DR, Schurman DJ, *J Orthop Res*, 3:435-446, 1985.

A Unifying Principle Relating Stress to Trabecular Morphology. Fyhrie DP and Carter DR, *J Orthop Res*, 4:304-317, 1986.

Contact Finite Element Stress Analysis of Porous Ingrowth Acetabular Cup Implantation, Ingrowth, and Loosening. Rappaport DJ, Carter DR, Schurman DJ, *J Orthop Res*, (in press).

Relation of Coxarthrosis to Stresses and Morphogenesis: A Finite Element Study. Carter DR, Rappaport DJ, Fyhrie DP, Schurman DJ, *Acta Orthop Scand* 58 (in press), 1987.

Trabecular Bone Density and Loading History: Regulation of Connective Tissue Biology by Mechanical Energy. Carter DR, Fyhrie DP, Whalen RT, *J Biomech* 20:785-794, 1987.

Femoral Head Apparent Density Predicted from Bone Stresses. Fyhrie DP and Carter DR, *J Biomech*, (in press).

Effects of Ingrowth, Geometry, and Material on Stress Transfer Under Porous Coated Hip Surface Replacements. Fyhrie DP, Carter DR, Schurman DJ, *J Orthop Res*, (in press).

Although widely used clinically, two investigations have concluded that the use of diphosphonates is ineffective in preventing heterotopic bone formation.

The purpose of the proposed research is to elucidate biomechanical and histological effects of drugs and radiotherapy on bone growth into porous coated Ti-6Al-4V alloy implants in canines. The study will include 50 adult beagles which will receive 4 bilateral transcortical porous coated implants. The animals will be divided into 5 groups, four of which will undergo therapeutic treatments for heterotopic ossification. Group A will serve as the control group. Group B will undergo 2 weeks of pre-operative dosages of diphosphonates, followed by 4 weeks of

post-operative treatments. Group C will undergo 4 weeks of post-operative diphosphonate therapy with no pre-operative treatments. Group D will be treated for 4 weeks post-operatively with indomethacin. Group E will undergo radiation treatments to bilateral femora for 5 consecutive days post-operative for a total dosage of 250 rads.

Implantation surgery will consist of the surgical placement of 4 transcortical porous coated implants per femora. Each animal will undergo bilateral procedures. At 4, 8, 12, 24 and 48 weeks post-operative, the animals will be sacrificed. Bilateral femora will be harvested and prepared for push-out

testing in order to determine the mechanical shear strength of the bone/implant interface. Some sections will remain intact for quantitative histologic evaluations of direct bone apposition and bone growth into the porous coated implants. The effect of each treatment modality will be evaluated in relation to implantation time, radiographic appearances, and *ex vivo* testing. The results of this investigation will help elucidate the optimal treatment for ectopic ossification with the minimal hindrance to bone ingrowth and stability of implant fixation.

Human In Vivo Acetabular Pressure Movement

John McA. Harris, M.D.

Veterans Administration Medical Center, Jamaica Plain, Boston, MA 02108

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Major hip surgery is conducted several hundred thousand times each year in the United States, including repairing the natural joint following fracture, replacing the femoral head only, and total hip joint replacement. Despite the frequency of these procedures and the dominant role the hip joint plays in human mobility, there has been virtually no reliable experimental data on the mechanical environment the hip joint experiences in life. Over the past two decades, several attempts to instrument components of partial or total hip replacement to measure the force vector at the hip joint have produced either meager or contradictory data over a very short postoperative period—or have failed completely.

Progress—More recently, a pressure-instrumented femoral head replacement was designed, fabricated, and tested at MIT. It was inserted into a consenting patient who required femoral head replacement at the Massachusetts General Hospital and has consistently produced reliable data over the entire period from implantation through 3 years of successful performance as a replacement joint and a research instrument. The prosthesis telemeters pressure at 10 discrete locations on the artificial femoral head, thus establishing the pressures experienced by the spatially corresponding locations on the natural acetabular cartilage against which the fem-

oral head articulates. Each transducer is sampled 250 times a second, thus faithfully recording all transient and dynamic events.

Pressure data were acquired during surgery, during immediate post-surgical recovery, during pre-rehabilitation bedrest and patient management, through all phases of rehabilitation and mobility training, and periodically as the subject progressed into normal activity. During all movement-related experiments, the pressure data were augmented by concurrent body-segment kinematic data using the MIT-developed TRACK system, dual forceplates, and more recently the myoelectric signals from the major muscular groups crossing the hip.

Results—Certain aspects of this *de novo in vivo* pressure data were anticipated, based on extensive prior *in vitro* series on cadaverous joints in the MIT Newman Laboratory. However, other features of the pressure data *in vivo* have been surprising—in particular the extreme pressures experienced and their orientation during certain activities such as rising from a low chair, when high muscle co-contraction forces across the joint are added to normal gravitational and inertial forces.

The data from this single implantation are already influencing surgical procedures in hip reconstruction, in particular the buttressing of the pelvic structure, and is challenging many rehabilitation

protocols that traditionally are based on subjective evaluation, patient recovery, and performance. The data from the implanted subject has also been followed very carefully as a source of information on which to base alterations and improvements in the design, fabrication, and implantation of subsequent prostheses.

Future Plans/Implications—Since hip reconstruction is a very common procedure among the aging veteran population, the Veterans Administration Rehabilitation Research and Development Service has funded an effort that will prepare and implant up to six more prostheses. This will generate more statistically significant data and provide the basis for recommending changes in surgical and rehabilitation practices following hip repair and partial and total hip replacement.

The extraordinarily high pressures (recorded during movements such as stair climbing and rising from a low chair) which require stabilization of the hip joint, presumably by means of co-contraction of the major muscle groups across the joint, have resulted in a decision to add electromyographic muscle activity information—the pressure kinematic and foot-floor force data flow. Given the complexity and high rate of the extant data flow and computer acquisition thereof, the addition of synchronized multichannel EMG was not a trivial task. A custom multiplexor was designed and fabricated to both reduce the number of wires connecting the experimental subject to the data acquisition system and to more efficiently integrate the EMG data into the data recovery, management and storage system. During several subsequent experimental periods, EMG data was acquired successfully and confirmed the role of co-contraction as the major source (beyond gravitational weight and inertial contributions) to the very high pressure magnitudes and directions observed during certain movement patterns.

Although the implanted prosthesis has performed extraordinarily well, certain improvements and alterations are under design consideration. These include mechanical clamping versus epoxy cementing of the transducer solid-state sensor, a channel

in the head hemisphere to provide stress relief during equatorial welding, relocation of the pressure transducers to more optimal positions in relation to acetabulum cartilage, incorporation of a temperature-sensing data channel, use of recently available commercial large-scale integrated circuit components, and improvements in the welding and polishing techniques. Following long-term testing *in vitro*, these will be incorporated into the prosthesis design.

The data acquired thus far and the performance of the instrumentation provides high assurance that additional implantations and subsequent testing will generate a novel and extremely valuable source of data that, for the first time, will establish with confidence the mechanical environment of the human hip joint in life, and that will provide the basis for quantitatively-based recommendations for improvements in surgical and rehabilitation protocols.

Publications Resulting from This Research

- A Precision PAM-FM Multichannel Implantable Patient-Monitor Telemetry System.** Burgess RG, Mann RW, *9th Annual IEEE EMBS Conference*, Boston, MA, November 1987.
- Investigation of In Vivo Loading Rate Characteristics in a Human Hip Joint.** Carlson KL, Hodge WA, Fijan RS, Mann RW, Harris WH, *Proceedings, RESNA 10th Annual Meeting*, San Jose, CA, 1987.
- Arising from a Chair: The Role of Bi-Articular Muscles in Resolving Lombard's Paradox.** Catani F, Hodge WA, Mann RW, *9th Annual IEEE EMBS Conference*, Boston, MA, November 1987.
- Hip Dynamics in Level Walking, Stair Climbing and Rising from a Chair.** Catani F, *ASME Winter Annual Meeting*, Boston, MA, December 1987.
- Myoelectric Crosstalk in Antagonist Muscles of the Human Thigh.** Emley M, Catani F, Roy S, Knaflitz M, *9th Annual IEEE EMBS Conference*, Boston, MA, November 1987.
- Contact Pressures in the Human Hip Joint Measured In Vivo.** Hodge WA, Fijan RS, Carlson KL, Burgess RG, Harris WH, Mann RW, *Proceedings of the National Academy of Science, USA*, 83:2879-2883, May 1986.
- The Influence of Hip Arthroplasty on Stair Climbing and Rising from a Chair.** Hodge WA, Zimmerman S, Riley PO, Mann RW, *ASME Winter Annual Meeting*, Boston, MA, December 1987.
- Pressures Measured In Live Hip Joint.** Lewin R, *Science* 232:1192-1193, June 1986.
- Rehabilitation Implications of In Vivo Hip Pressure Measurements.** Mann RW, Carlson KL, Burgess RG, Fijan RW, Hodge WA, Harris WH, *Proceedings, RESNA 9th Annual Conference*, Minneapolis, MN, 1986.
- Application of Biomechanics to Human Rehabilitation.** Mann RW, *Proceedings RESNA 10th Annual Conference*, San Jose, CA, 1987.

Initial Stability of Orderly Oriented Wire Mesh Porous-Coated Implants

Bruce R. Heppenstall, M.D.; Paul Ducheyne, Ph.D.; Charles Cohen, B.Sc.; Enrique Nazar, M.D.; John Cuckler, M.D.

Orthopaedic Research Laboratories, Veterans Administration Medical Center, Philadelphia, PA 19104 and School of Engineering and Applied Science, The University of Pennsylvania, Philadelphia, PA 19104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Three-dimensional finite element analyses have been performed to evaluate the comparative long-term stress distribution in canine hips revised with various porous titanium materials, versus canine hips reconstructed with only bone cement. In addition, the placement of the porous structure was also varied with respect to a cortical medial defect created to mimic the situation at revision of a loosened prosthesis.

Progress—In a first phase, perfect bonding is assumed. This assumption benefits the case with bone cement, as clinical evidence clearly indicates considerable loosening with the revision prosthesis as well. A slight beneficial effect is noted with the use

of the porous materials; at the distal stem tip, stresses considerably closer to the physiologic stresses are noted.

In clinical practice, bone cement is unable to achieve good bonding with the smooth endosteal cortex present at revision surgery. Thus, we are expanding our calculations to allow for debonding at the cement interfaces. We insert frictional gap elements at the interface between cement and bone. The theoretical stress data are analyzed in conjunction with experimental mechanical test data obtained on actual canine hip reconstructions using the modeled materials, and excised at 3 weeks and 3 months after surgery.

Skeletal Aging and Disease in Failure of Hip Surface Replacement

A.A. Hofmann, M.D.; A.U. Daniels, Ph.D.; K.N. Bachus, M.S.

Orthopedic Histomorphometry Laboratory, Veterans Administration Medical Center, Salt Lake City, UT 84148 and Orthopedic Bioengineering Laboratory, Division of Orthopedic Surgery, University of Utah School of Medicine, Salt Lake City, UT 84132

Sponsor: VA Rehabilitation Research and Development Service and Division of Orthopedic Surgery, University of Utah School of Medicine

Purpose—Surface Replacement Hip Arthroplasty (SRHA), in comparison to conventional Total Hip Arthroplasty, has the advantages of replacing the diseased hip surface while preserving normal bone stock, maintaining more normal physiological bone load patterns, providing an easier method for replacement of failed implants, and decreasing the occurrence of deep infection in the femur subsequent to surgery. However, these advantages have been offset in clinical practice by high failure rates, mainly due to early loosening of the femoral and/or acetabular components.

The objectives of this project are to determine causes of early loosening in SRHA, and relationships between these causes and skeletal aging and disease. The possible causes for SRHA failure include: 1) Poor initial fixation due to inadequate operative

techniques and instrumentation; 2) Bone necrosis secondary to disruption of the blood supply; 3) Inadequate (age/disease-related) initial bone strength; and, 4) Bone remodeling due to stress redistribution, related either to prosthesis design or to processes of aging and disease.

Progress/Preliminary Results—The data obtained from this study will be used to determine the viability of SRHA and, if possible, to design improved components and techniques. The major accomplishments during the past year for this study are:

1) Three-dimensional mapping of the trabecular bone mechanical compressive strength of the femoral head has been completed. The regions of high compressive strength were similar for both healthy and diseased bone and were located in the superior

medial portions of the femoral head. The anterior half of the femoral head had a slightly larger compressive strength than the posterior half. A manuscript entitled "Compressive Strength Mapping of Femoral Head Trabecular Bone" has been submitted to the *VA Journal of Rehabilitation Research and Development* (JRRD).

2) To increase the analysis speed and accuracy of data obtained from studies using histological and/or Back-Scattered Electron Imaging (BEI) techniques, a PC-compatible, computerized digitization program has been developed.

3) Following a presentation entitled "Increased Endosteal Bone Loss After Hip Arthroplasty," given at the 1986 Orthopedic Research Society meeting, a manuscript, entitled "Increased Endosteal Bone Loss After Hip Arthroplasty," has been submitted to *Clinical Orthopedics*.

4) A preliminary study has been completed for radioisotope-based determination of femoral head vascularity in SRHA patients. Technetium-99m (T-99m) HDP and MDP-based bone scanning and tissue scintillation counting techniques were applied to canines subjected to mock SRHA surgery in order to evaluate the ability of such techniques to measure changes in femoral head vascularity due to surgical stripping of the hip capsule. Results indicated that canine capsule disruption acutely inhibited blood flow and reduced vascularity by 30 to 70 percent in the surface bone of the femoral head. A manuscript is being submitted to the *VA Journal of Rehabilitation Research and Development*.

5) A study to correlate bone remodeling with prosthesis materials and design is in progress. Test cylinders of either porous cobalt-chrome, porous titanium, or hydroxyapatite-coated porous titanium are being implanted into the cancellous crests of

consenting bilateral total joint replacement patients. After 6 to 8 weeks, these test plugs are removed with a small portion of attached bone for back-scattered electron imaging and histomorphometric analysis of the bone-implant interface. Initial results indicate that hydroxyapatite-coated porous titanium implants induce the fastest rate of bone ingrowth and bone ingrowth into cobalt-chrome was slowest. Abstracts, entitled "Histological Analysis of Tissue Ingrowth into Porous and Hydroxyapatite-Coated Metal Test Plugs Implanted into Human Cancellous Bone" and "Human Cancellous Bone Ingrowth into CC and Ti Porous Coated Implants—A Backscattered Electron Microscopic Analysis," were submitted for presentation at the 1988 Orthopedic Research Society meeting.

6) A pilot implant retrieval study has been initiated to help determine the long-term changes that occur in total joint replacement components and adjacent tissues. To date, 53 patients have consented to participate in this study, and 19 joint prostheses have been retrieved during revision surgery and are under analyses. The information obtained will be of considerable value in the design of improved prostheses.

Future Plans/Implications—Principal project activities for the next few months will include continued collection and processing of specimens and analysis of data for relationships between prosthetic design and bone remodeling. Whenever possible, SRHA patients who suffer from failed prostheses and are scheduled for hip replacement surgery will undergo both histological and scanning analysis. Efforts will be continued to increase the size and effectiveness of the implant retrieval program to provide more specimens for study.

Quantitative Analysis of Total Hip Arthroplasty on Cadaver Pelvis Stress and Strain

R.W. Petty, M.D. and Gary J. Miller, Ph.D.
Veterans Administration Medical Center, Gainesville, FL 32602

Sponsor: VA Rehabilitation Research and Development Service

Purpose—With the advent of new acetabular cup designs and techniques for total hip arthroplasty, researchers have hoped to improve the overall performance of this treatment modality for the

arthritic hip. Historically, little objective experimental information is available concerning the effect of the implantation of these devices on the stresses and strains developed in the human pelvis.

Progress—Using strain-gauge instrumentation, this long term investigation has quantified the effects of available prosthetic components on the strains in the cadaver hemipelvis. Based on the premise that pelvic strain changes following implantation may predict the long-term success or failure of arthroplasties of the hip, various implant designs and techniques that do not significantly alter normal strain distributions of the pelvis have been determined.

Following the initial work, which led to the development of automated, computerized data acquisition systems and customized loading fixtures, assessment of various surgical techniques and cup designs on pelvic wall strains during simulation of single limb stance phase were recorded. Various techniques of implantation that were considered included the use of pilot holes, various reaming levels of subchondral plate, cement restrictors, and the use of spacers for insuring a uniform cement mantle.

Results—Our results indicated that the use of pilot holes and substantial reaming would lead to large increases in pelvic strain per unit applied load. An even cement mantle led to minimal changes in pelvic strain if the compliance of the acetabular component itself was appropriate.

The evaluation of cup design as it relates to implant compliance and the effect it has on pelvic strain was also determined. These results indicated that the early low-compliance standard polyethylene components tend to increase pelvic strain considerably, while thick CoCr metal-backed components led to unloading or stress protection of the cadaver hemipelvis in this loading configuration. Titanium-metal-backed prostheses and thin-shelled CoCr-metal-

backed components with spacers were found to lead to an intermediate result. Most recently, the evaluation of noncemented "screw-in" CoCr implants indicated that, while their compliance behavior was somewhat akin to the thicker CoCr, considerable hoop stresses were generated due to the insertion of the components themselves. Further research in this area is continuing with the evaluation of porous-coated metal-backed components and several newer designs. Thus, on the acetabular side, it appears that strain changes in the pelvis may be controlled with the control of implant compliance and insertion methodology.

Future Plans/Implications—This information, when coupled with early clinical results, should allow the determination of designs and methods of insertion that lead to minimal strain changes, and may therefore infer increased longevity of acetabular components.

Our evaluation of press-fit noncemented femoral components has initiated the use of a newly developed holographic interferometry technique. The clinical goal for this portion of the effort is to attempt to understand the complaints of thigh pain cited by many patients receiving these devices. Early results indicate discontinuities in curvature appearing at the distal tip of the prosthesis, and further work is continuing to determine the effect of quality of fit on these observed strain changes along the femoral shaft. The long-term goal of this portion of the research program is to develop a "noncontact" method for the evaluation of strains in bone for biomechanical applications in our continued desire to understand the performance of total hip arthroplasties and their interaction with the host skeletal system.

C. Knee

Design Concepts for a Porous-Ingrowth, Prosthetic Tibial Component

Gary S. Beaupré, Ph.D.; Dennis R. Carter, Ph.D.; David Schurman, M.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objective of this study is to develop design concepts for a porous-coated/bony-ingrowth tibial component of a total knee prosthesis.

Progress—Using mathematical models, we will develop design criteria for total knee replacements. Both the early and late stages of bony-ingrowth will be studied. The shortcomings of conventional implants will be examined and the predicted response using presently available implants will be compared to newly developed designs. We plan to use the bony architecture of the natural tibia as a design guideline.

The mathematical models are based upon the finite element technique. These models will provide us with information about the stress fields which exist in the proximal tibia before and after joint arthroplasty. We will use linear models to simulate the firmly attached prosthesis and nonlinear, friction interface models to study the newly implanted prosthesis. These later models will provide new data on the stress fields which exist immediately after a porous-coated prosthesis has been implanted, before bony-ingrowth has occurred.

For all models, the predicted stress distributions for each implant design will be compared with the trabecular morphology from cadaver tibiae to determine which designs will likely result in the least amount of remodeling.

Results—Linear, two-dimensional, equivalent-thickness models in both the frontal and sagittal planes have been developed for the natural tibia and for a variety of conventional and new tibial component designs.

Future Plans—A preliminary study using sub-models aimed at determining an optimal interface geometry are being developed. In addition, an experimental testing system is being designed to generate *in vitro* data on competitive fixation systems.

A new iterative, bone remodeling technique is being developed which will be used to predict the apparent density distribution caused by the presence of different types of implants. This technique will permit a critical and quantitative comparison of different types of prosthesis designs.

Publications Resulting from This Research

Finite element analyses of tibial component designs. Vasu, R., Carter, D.R., Schurman, D.J. and Beaupré, G.S., *Trans Orthop Res Soc* 10:123, 1985.

Bony-ingrowth components for the tibial plateau—A finite element analysis. Beaupré, G.S., Vasu, R., Carter, D.R. and Schurman, D.J., *Proceedings of the Eighth Annual Conference on Rehabilitation Technology RESNA*, Memphis, TN, 299-301, 1985.

Applications of a bone remodeling theory in the design of bony ingrowth prosthetic components. Carter, D.R., Fyhrie, D.P., Orr, T.E., Vasu, R., Beaupré, G.S. and Schurman, D.J., *Proceedings of the Third Biomaterials Symposium*, Göttingen, Germany, June 1987.

Application of a bone remodeling theory to femoral and tibial prosthetic components. Orr, T.E., Beaupré, G.S., Fyhrie, D.P., Schurman, D.J., and Carter, D.R., submitted to the 1988 ORS Society meeting.

Epiphyseal-based designs for tibial plateau components—I. Stress analysis in the frontal plane. Vasu, R., Carter, D.R., Schurman, D.J. and Beaupré, G.S., *J Biomech* 19:647-662, 1986.

Epiphyseal-based designs for tibial plateau components—II. Stress analysis in the sagittal plane. Beaupré, G.S., Vasu, R., Carter, D.R. and Schurman, D.J., *J Biomech* 19:663-673, 1986.

Advances in total joint replacement. Beaupré, G.S. and Carter, D.R., *VA R&D Newsletter*, February, 1987.

Ligament Insertions: Relations in the Moving Knee

John A. Sidles, Ph.D.; Theodore K. Greenlee, M.D.; Joseph L. Garbini, Ph.D.; Roger V. Larson, M.D.; Frederick A. Matsen III, M.D.

Department of Orthopaedics, University of Washington, Seattle, WA 98195

Sponsor: VA Rehabilitation Research and Development Service; National Institutes of Health

Purpose—In the surgical reconstruction of knee ligaments, an important goal is that the reconstructed ligament be neither too tight nor too loose as the knee flexes through a normal range of motion. Such reconstructions are termed isometric, since the reconstructed ligament does not change length during knee motion. The purpose of our research is to identify all of the attachment sites in the knee which are nearly isometric.

Progress—Our methodology involves detailed measurements of three-dimensional knee anatomy and six-degree-of-freedom knee motion. We use a six-degree-of-freedom digitizing sensor for this purpose. For each cadaver knee in our study, we measure motion of the intact knee under eight different loading conditions. The knee is then dissected, and its anatomy is digitized by hand at more than two thousand separate points. We then inspect the data, using animated three-dimensional computer graphics on an IRIS workstation to display knee motion and anatomy. Computer search techniques are then used to determine all possible nearly isometric insertion sites. The results are displayed graphically as color-coded three-dimensional "isometry maps," which show explicitly the degree of isometry available at each point on the femur or tibia.

To date we have measured ten knees, and have prepared and statistically analyzed more than fifteen hundred isometry maps for the anterior and posterior cruciate ligaments, for the medial and lateral collateral ligaments, and for lateral extra-articular tenodesis of the iliotibial band.

Results—We found three separate techniques suitable for isometric repair of the anterior cruciate ligament. These were: 1) tibial placement in the center of the anatomic ligament, with femoral placement high in the notch and 5mm forward from the back; 2) tibial placement at the anterior margin of

the anatomic attachment, with femoral placement 5 mm forward from the back and 8mm lateral to the roof of the notch; and 3) tibial placement in the center of the anatomic ligament, with over-the-top femoral placement. Technique (1) is presently our preferred clinical choice, because technique (2) has increased notch impingement, and technique (3) is isometric only from zero to thirty degrees of knee flexion.

For posterior cruciate ligament repair, we found that the isometric femoral sites were always located within the posterior margin of the anatomic attachment, approximately 15mm back from the front of the notch, 6mm medial and 5mm down from the roof. For lateral extra-articular tenodesis of the iliotibial band, we found that isometric femoral sites were located directly posterior to the lateral epicondyle, approximately 60 percent of the way to the articular margin.

Clinicians are cautioned that these results are valid only for single fibers. Real grafts are complex bundles of interacting fibers, and this must be taken into account when planning reconstructive surgery.

Future Plans/Implications—There is a clear need to better understand the behavior of both anatomic ligaments and grafts as complex structures, rather than single idealized fibers. We are currently developing a general theory of the mechanics of fiber-fiber interactions in flexible structures. With this theory, we hope to address a number of questions of potential clinical significance. These include: 1) nonuniform strain of peripheral fibers in a finite graft; 2) the effects of fiber bending at bone tunnels; and 3) the effect of deliberately inducing intra-articular twisting of the graft.

Publications Resulting from This Research

Ligament Length Relationships in the Moving Knee. Sidles JA, Larson RV, Garbini JL, Downey DJ, Matsen FA, *Journal of Orthopaedic Research*, in press.

Design of External Joint Assemblies (EJAs) Using CAD/CAM Techniques

Peter S. Walker, Ph.D., and Peter Elliot, BSME
Veterans Administration Medical Center, Brockton, MA 02401

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—The goal of this project is to obtain an extended data base for 3-D knee motion on specimens and human subjects and to manufacture external knee surfaces using a CNC machine.

Progress—The work has involved the development of an automated method for measuring 3-D knee motion on human subjects, the design of an apparatus for describing 3-D body surface shape, and the use of these techniques to explore upper extremity orthoses.

Preliminary Results—A new 3-D knee motion anal-

ysis paradigm has been developed, using a unique tibial and femoral fixture, and data collection on human subjects is under way. An apparatus was designed and tested for measuring the 3-D body surface shape ("Magic Fingers"). We are at the stage of polishing the software that will be modifiable for various applications. A myoelectric upper extremity orthosis for C5-C7 SCI patients has been developed. The effort is concentrated around independent usage of the device that will enable a variety of shoulder, elbow and hand movements. Clinical testing of the hand orthosis alone is under way.

All-Plastic Total Knee Replacement

**Peter S. Walker, Ph.D.; Richard F. Rodger, D.V.M.; Alan L. Schiller, M.D.; Peter Elliot, BSME;
Robert Schrager, BSEE**

Veterans Administration Medical Center, Brockton, MA 02401

Sponsor: *VA Rehabilitation Research and Development Service*

Progress—The objective is to develop a total knee replacement made entirely from injection-moldable polymer. The research plan is to measure the friction wear of candidate materials, to carry out cyclic load tests of fabricated joints, and to test out total knees in sheep. Multicomponent force transducers are used which will measure the frictional force and downward force administered to reciprocating wear

samples. Data obtained are compared to that of physiological tissue in joints for ideal biocompatibility.

Results—The completed machine is currently undergoing instrumentation calibration. The test materials have been chosen and procured.

Evaluation of Knee Performance After Various Orthopaedic Procedures

M. Solomonow, Ph.D., and R. D'Ambrosia, M.D.
Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: *LSU Department of Orthopaedics*

Purpose—The objective of this study was to quantify knee performance before and after various surgical procedures in order to provide the surgeon with guidelines as to the efficacy or superiority of one

procedure over another, or possible modification of a procedure which would allow improvement of the patient's ability and performance in an optimal mode.

Progress—Several patients with chondromalacia, some who underwent simple debridement, and others who were treated with the Macquet procedure, were evaluated during maximal-effort, isokinetic knee flexion and extension with simultaneous re-

cording of musculature EMG. Data of each patient was integrated with pre-surgical performance, radiological analysis, and compared with performance of normals in order to establish comparative evaluation guidelines.

IV. Spinal Cord Injury

A. General

Clinical Evaluation of External Devices for Urinary Care of Incontinent Women

David E. Johnson, Ph.D. and Jodie L. O'Reilly, R.N., B.S.N.

Veterans Administration Medical Center, Infectious Diseases Research Laboratory, Baltimore, MD 21218

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Chronic urinary incontinence, a frequent complication of spinal cord injury, multiple sclerosis, neurological defects affecting frontal lobe cortex, and advancing age, may be the pivotal factor determining whether a patient requires long-term institutional care. An estimated 2.4 million American women are incontinent of urine and that number is likely to exceed 3 million by the year 2000. This report summarizes our ongoing studies into the development of comfortable and effective external devices for women as alternatives to indwelling urethral catheters and/or absorbent products.

The customary methods for management of chronic urinary incontinence in women, the use of indwelling urethral catheters or diapers, invariably lead to bacteriuria or infected decubiti in nonambulatory patients. An external device that was comfortable to use, and effective in collecting urinary output without leakage, may prevent some of the complications (e.g., bacteriuria and infected decubiti) associated with management of chronic urinary incontinence.

Progress—We have entered into joint studies with device manufacturers for development and clinical evaluation of external urinary incontinence devices for women. These joint studies include fabrication of prototype devices by the manufacturers, and our clinical evaluation of prototypes in healthy volunteers and urinary incontinent inpatients and outpatients.

Since our last report, we have clinically evaluated five types of external urine-incontinence devices for women. Three of those device types were designed for use by ambulatory women and two of those

devices were designed for use by non-ambulatory women.

We have evaluated 256 applications of external devices in 13 ambulatory, urine-incontinent women. Time of device use per day varied and was determined by individual patient needs. Devices were evaluated on the basis of ease of application and removal by the patient, adverse consequences of device use including unacceptable urine leakage from the devices, and patient comfort during device use. Patients were able to self-apply and remove devices without consequence.

Results—Forty percent of device applications resulted in urine collection without leakage and 10 percent of applications resulted in sufficient urine leakage to force the patient to temporarily use an alternative method of urinary care.

We have clinically evaluated 116 applications of external devices in 14 bedridden women. Preliminary studies were conducted using healthy volunteers confined to bed for 8 hours per day for 5 days, for device evaluation. Periurethral irritation was not observed during device use, and devices remained *in situ* without urine leakage for 97 percent of the evaluation period.

We have also evaluated 63 applications of an external device for 125 patient days on 7 bedridden, urine-incontinent nursing home patients. Five patients used the device continuously for 21 days, and 2 patients used the device continuously for 10 days. Devices were allowed to remain *in situ* while effective (i.e., collecting urine without leakage) for a maximum of 48 hours, but were replaced if leakage occurred. Mean effective wear time (\pm S.D.) of the

device was 45.6 (\pm 5.7) hours. Periurethral irritation was not observed in those nursing home patients during device use.

Future Plans—Evaluation of device modifications in ambulatory, urine-incontinent women. Evaluation of continuous device use in bedridden, urine incontinent women for up to 6 months.

Electrical Stimulation for the Prevention of Pressure Sores: Blood Flow Measurements

Simon P. Levine, Ph.D.; Ronald L. Kett, M.S.; Milton D. Gross, M.D.; Jack E. Juni, M.D.; Barbara A. Wilson, B.S.

Rehabilitation Engineering Program, Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center, Ann Arbor, MI 48109 and Nuclear Medicine Service, Ann Arbor Veterans Administration Medical Center, Ann Arbor, MI 48105

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Pressure sores (decubitus ulcers, ischemic ulcers, etc.) represent a severe and costly problem for many disabled individuals. This is particularly true for those who are wheelchair-dependent and have sensory loss. A research program has been implemented to determine whether electrical muscle stimulation (EMS) can be used to prevent the formation of pressure sores.

Pressure sore etiology is a complicated event, involving many parameters, but most investigators agree that a primary event leading to pressure sore formation is blood flow occlusion. Occlusion of lymph flow and disturbance of interstitial fluid flow are also important factors. The current study investigates the effects of EMS on tissue blood flow.

Progress—The scope of the current project is to investigate those “immediate/dynamic” effects of EMS for preventing pressure sores. One of the hypothesized mechanisms whereby EMS may be effective is that tissue undulation and variations in the seating interface pressure will permit increased blood flow. Previous reports have documented that EMS can produce substantial interface pressure changes. This is true even at low stimulation intensities easily tolerated by sensate subjects. It has also been shown, using an ultrasonic image acquisition system, that EMS will produce appreciable tissue shape changes.

Preliminary Results—Blood flow in the skin and muscle during stimulation has been studied by injecting a radioactive tracer into the tissue. These blood flow studies have been performed on eight able-bodied (AB) and nine spinal cord injured (SCI)

subjects. All SCI subjects had acute injury at level T10 or above. One individual had incomplete injury; the rest were sensory and motor complete. None had a history of pressure sores at their ischial tuberosities (IT).

Bilateral stimulation of the gluteus maximus muscle was performed using surface electrodes and a commercially available neuromuscular stimulator. The stimulation protocol for the AB subjects was as follows: a) 30 minutes, no stimulation; b) 12 minutes, alternating 2 minute periods of stimulation and rest; c) 30 minutes, no stimulation. Protocol for the SCI subjects differed only in that the initial and final 30 minute rest periods were reduced to 20 minutes. Pressure measurements were also recorded during the trial for comparison of blood flow with the magnitude of muscle contraction.

Blood flow was measured by injecting $^{133}\text{Xenon}$ at the site of the IT. Each subject received a subcutaneous injection on one side and an intramuscular injection contralaterally. A gamma camera with collimator was positioned under the subject. Sequential scintigraphic images of the injection site were recorded throughout the trial. Following imaging, a time-activity semilogarithmic plot of the $^{133}\text{Xenon}$ washout was obtained where the slope is proportional to the blood flow. For the AB subjects, blood flow in the muscle was increased significantly ($p < .05$) when compared to blood flow preceding or following EMS intervention. The SCI subjects showed the same trend; however, statistical significance was reduced ($p < .15$). This technique was ineffective for measuring subcutaneous blood flow due to the lipophilic nature of xenon.

Future Plans/Implications—Measurement of skin blood flow is an important part of evaluating the potential efficacy of EMS for pressure sore prevention. However, $^{133}\text{Xenon}$ has proved ineffective in measuring subcutaneous blood flow. Consequently, an alternate material, $^{99\text{m}}\text{Technetium}$ will be used. Trials have already begun with intradermal injections of this new radioactive material. Clinical trials, to directly determine the effect of EMS on skin status while sitting, are also planned for the near future. New SCI subjects will be recruited from the population of inpatients in the Interdepartmental Acute Spinal Cord Injury Program at the University

of Michigan Medical Center.

Publications Resulting from This Research

Dynamic Effects of Functional Electrical Stimulation on Seating Interface Pressure and Tissue Shape. Kett RL, Levine SP, Bowers LD, Brooks SV, Cederna PS, *Proceedings of the 9th Annual RESNA Conference*, 6:313-315, Minneapolis, MN, June 1986.

Functional Electrical Stimulation for the Prevention of Pressure Sores. Levine SP, Cederna PS, Brooks SV, Friedman RH, *Proceedings of the 7th Annual Conference—IEEE Engineering in Medicine and Biology Society*, pp. 707-710, 1985.

Ischial Blood Flow of Seated Individuals During Electrical Muscle Stimulation. Levine SP, Kett RL, Wilson BA, Cederna PS, Gross MD, Juni JE, *Proceedings of the 10th Annual RESNA Conference*, 7:642-644, San Jose, CA, June 1987.

Factors Influencing Joint Compliance and Reflex Mechanisms in Spinal Cord Injury

Charles J. Robinson, D.Sc.; Gyan C. Agarwal, Ph.D.; Gerald L. Gottlieb, Ph.D.

Veterans Administration Medical Center, Hines, IL 60141 and University of Illinois, Chicago, IL

Sponsor: VA Rehabilitation Research and Development Service (Project #XB446-R)

Purpose—The normal pattern of motor control is greatly altered by spinal cord injury (SCI), often in unpredictable fashion. Much of the characterization to date of reflex activity in individuals with spinal cord injury comes from studying electromyographic responses to peripheral nerve stimulation, not to passive or active limb movement where joint compliances can be measured. While controlled passive movements can be achieved with torque motors, active movements in some of these individuals can be initiated with surface electrical stimulation. Restrengthening of paralyzed muscles by such stimulation also might alter compliance and reflex activity.

The following questions will be addressed in this project. Can joint compliance and spinal cord and supraspinal reflex activity be reliably measured in individuals with SCI? How does this activity change over the time since injury? Do joint rotations yield a more complete and reliable characterization of the peripheral motor control loop than do measurements of H-reflex changes? Are the compliances and reflexes different when the muscles are being activated by electrical stimulation? Does electrical muscle reconditioning alter compliance and reflex activity?

The research will be based on the following hypotheses. 1) Any treatment or pathological course that alters a muscle's capability for volitional movement, response to electrical stimulation, or reflex

excitability will be reflected in appropriate measures of joint compliance and reflex activation that are obtained by measuring mechanical and electromyographic responses to mechanical perturbations of the joint. 2) In adult-onset spinal cord injury, joint compliances and reflexes will change in a characteristic fashion that depends on the level and completeness of the injury: a) during the evolution of spinal cord injury (i.e., during the first 6 months post-injury); b) following 1 week controlled removal of anti-spasmodic medications in individuals with chronic (1 year post) spinal cord injury; and, c) following a 4-week period of electrical muscle reconditioning. 3) The changes in joint compliance will correlate with changes in residual supraspinal influences since measurements of joint torque and angle should be more physiologically appropriate.

The following research techniques will be employed. We will measure the time pattern of joint compliance at elbow, ankle, and knee using step and sinusoidal mechanical perturbations of limb position; EMGs and stretch reflexes of appropriate muscles; and H-reflex at Soleus. We will set the limb position passively or by volitional effort (if possible) or electrical stimulation and compare results. We will check for supraspinal influences. The populations to be studied are: 1) neurologically intact; 2) motor impaired due to spinal cord injury;

3) motor paralyzed—tonic; and, 4) motor paralyzed—flaccid. Intervention: If less than 6 months post-injury, we will monitor changes in measures over time for groups 2 and 3 above and compare with sequelae. If greater than 6 months post-injury, we will measure and then attempt to restrengthen paralyzed muscles of groups 2 and 3 above, then remeasure. We will compare subject responses while receiving long-standing clinically prescribed anti-spasmodic medications to that obtained on drug holiday. We will use the neurologically-intact subjects and the flaccid-paralyzed subjects as controls.

The project will cover a 3-year period. During the first year we will concentrate on ankle joint; in recently injured SCI patients (4 to 6 “complete,” 4 to 6 “incomplete”), compare joint compliance, EMGs, mechanically and electrically (H-reflex) induced reflexes, supraspinal influences, and volitional and electrically stimulated muscle strength. We will trace changes in these comparisons as the rehabilitation of the individual progresses. Just before discharge, subjects will be put on 1-week drug holiday, then remeasured. In the second year, we will continue these activities, but will also include knee and elbow joints (compared cervical with thoracic lesions). In the third year, we will test the effect that a 4-week

program of electrically induced exercise has on these measures for patients who are more than 6 months post-injury.

Parellel measures of joint compliances, stretch reflexes, and H-reflexes, while correlated, are not redundant. They provide complementary information about various aspects of the peripheral motor control loop and phasic and tonic supraspinal influences on alpha, gamma, and intraneuron motor pools. But, for spinal cord injured individuals, these measures might differ in their sensitivity to time-post-injury, drug removal, supraspinal influences, and electrical muscle stimulation (both in the short- and long-term). Indeed, a comparison of their respective sensitivities is a purpose of our proposed research. For the SCI patient, a spastic limb can be socially embarrassing, can put the patient medically at risk of bone fracture, abrasions, decubiti and joint ossification, and can hinder functional rehabilitation. This present proposal seeks to characterize joint compliance changes during the evolvement of spinal cord injury. If such a characterization tracks the evolvement and is sensitive to drug holiday, then later efforts can be directed using it clinically to quantitate spasticity.

A Pilot Project on Skin Blood Flow Response to Loading

A.H. Sacks, Ph.D., and Inder Perakash, M.D.

Rehabilitation Research and Development Center and Spinal Cord Injury Center, VA Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service (Pilot Proposal #B924-PA)

Purpose—During the past year and a half, we have been conducting skin blood flow studies using a noninvasive laser Doppler instrument to measure alterations in skin blood flow with the application of external pressure loading. The significance of such studies lies in their possible use for identifying those patients who may be particularly susceptible to developing pressure sores. As a result of those efforts, we have made two major observations, both of which have now been reported at meetings and published. First, by application of an engineering technique known as dimensional analysis, we have found that one need not measure applied pressure, but it is essential to measure both skin deformation

and bone depth. Second, the laser Doppler flowmeter, when used at high loadings, gives a signal which does not accurately measure blood flow.

This proposed pilot project would seek to accomplish two goals: 1) use a new experimental setup and apparatus with the laser Doppler which keeps measurements in the low loading range where the instrument is believed to be accurate; and, 2) conduct sufficient preliminary experiments to demonstrate whether or not the use of dimensional analysis does indeed result in a clearer separation of subject groups than could be achieved by more conventional measurements.

Activities of the Georgia Regional Spinal Cord Injury Center

David F. Apple, Jr., M.D. and Lesley M. Hudson, M.A.
Shepherd Spinal Center, Atlanta, GA 30309

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—The purpose of the model system concept is to develop a model system of care for the spinal cord injured population in various sites nationwide (13), and collaborate on research questions involving the data collection effort. The program has been in existence since 1971. The Georgia Regional Spinal Cord Injury Center is one of two such models in the Southeastern region of the United States.

Progress—The methodology of the project is to demonstrate the effectiveness of the model of care which seeks to positively affect each major stage of treatment following traumatic spinal cord injury: EMS Treatment and Transport; Emergency Room Treatment; Acute Care; Rehabilitation; and Follow-Up. Additionally, research projects, both single site and collaborative within the system are required of each model system, based on extensive data collection on all acute admissions, which become part of an 11,000 patient national database which is housed at the University of Alabama/Birmingham National SCI Statistical Center. Progress at the Georgia facility has occurred in the areas of employment, outreach clinic programs, prevention and peer support. Research is currently underway at that location on educational and learning patterns, high quadri-

plegia considerations, family intervention in the return to work, deep venous thrombosis incidence, and atelectatic treatment modalities.

Preliminary Results—Results of the demonstration portion of the project have shown a marked improvement in length-of-stay figures, post-discharge medical complications and overall cost under the system approach to care, with early referral to the system, versus non-system treatment. Employment efforts have resulted in an increase in the percentage of patients who are able to return to gainful employment following injury. Outreach clinics have delivered treatment in the field to patients who were noncompliant with the existing outpatient clinic facilities of the Shepherd Spinal Center. All research projects, both single site and collaborative, are underway and are expected to continue through 1990. Results will be published at the conclusion of these projects.

Future Plans/Implications—The current award will terminate in September of 1990. The scope of work is fixed until that time, and future plans beyond that are still in the preliminary stage.

On the Reduction of Energy Requirements for Crutch Ambulation by Paraplegics

Dudley S. Childress, Ph.D. and Robert L. Van Vorhis, M.S.
Rehabilitation Engineering Program, Northwestern University, Chicago, IL 60611

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—Crutch walking facilitates increased mobility for a person with paraplegia. Swing-through ambulation is a relatively fast crutch-assisted gait modality but has associated with it high levels of energy expenditure. The objective of this study is to establish what aspects of crutch-assisted swing-through gait by persons with paraplegia are energy intensive and to establish methods to reduce these energy expenditures. The hypothesis is that efficient

crutch ambulation is feasible for the paraplegic ambulator.

Progress—This study expands a preliminary investigation performed at this laboratory entitled, *Kinematic and Pendular Aspects of Swing-Through Paraplegic Crutch Ambulation* (Rovick, J.S., M.S. Thesis, Northwestern University, 1982). Rovick examined the kinematics of swing-through para-

plegic crutch gait and modeled the gait with mathematical models which were based on physical principles. His work indicates three main areas of energy expenditure. These are: 1) the energy required in stabilization of the joints (e.g., elbow and shoulder); 2) the energy lost in muscular effort for elevating the body to allow the feet to clear the ground; and, 3) the energy used to control the motion of the trunk. A major focus of this study is to try and eliminate the significant lifting of the trunk and legs to facilitate floor clearance during the swing-phase. It is anticipated that by eliminating or reducing the energy expenditure associated with the mechanical work of lifting, there may also be reduction in energy expenditure associated with control of the motion of the trunk.

Our plan is to utilize both crutch lengthening (via a rocker modification of the crutches) and leg shortening (via ankle control) as means of facilitating ground clearance without energy-intensive lifting. The models of Rovick will be modified and used as conceptual design tools. Walking trials will be performed. The mechanical work of subjects with paraplegia during normal and modified swing-through gait will be compared. Mechanical work is calculated from its basic definition (the product of joint moments and joint velocity). To obtain useful results, high-accuracy, high-sampling-rate positional data is required along with measurement of feet and crutches floor reactions. The major focus of our efforts has

been the development of a motion analysis facility. This system is based on the CODA-3 Movement Monitoring Instrument and includes two AMTI biomechanics platforms. The collection of data during clinical walking trials has been delayed during this development.

Results—Completion of the gait laboratory was scheduled for the Fall of 1987. The validity and sensitivity of the mechanical work calculations will be done in the Fall and Winter of 1987. Evaluation of strategies for energy reduction will then begin.

Implications—Establishing a technique for efficient swing-through crutch ambulation can provide the paraplegic ambulator with an additional option from which to choose a gait modality. We believe it will be some time before functional neuro-muscular stimulation (FNS) systems can adequately provide dynamic postural control (balance) during ambulation. Therefore, even with sophisticated bipedal stimulation systems, crutches will likely be used. The gait modality of efficient and fast swing-through crutch ambulation would complement a bipedal FNS system as well as provide an alternative to wheelchair ambulation. It is hoped that the feasibility of reducing the energy demand of swing-through crutch ambulation by persons with paraplegia can be established and a technique with clinical potential can be realized.

Retrospective Analysis of the National Spinal Cord Injury Care System Database

Michael J. DeVivo, Ph.D.

Research and Training Center in Spinal Cord Dysfunction, University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—Systematic and comprehensive management of acute spinal cord injury (SCI) is directed towards reducing morbidity and mortality, increasing life function capacity, and minimizing costs of care associated with this catastrophic condition. Accordingly, it is desirable to establish a mechanism to evaluate performance of the organized management system addressing desired outcomes in such a way that the impact of the system, compared to other pre-system or parallel non-system activities,

is clearly defined.

Further, assessment of system performance over time is essential to establish patterns of behavior which may then serve as a basis for implementing practice, policy, or programmatic change(s), if necessary. This study is evaluating, retrospectively, the performance of the Model Regional Spinal Cord Injury Care System, emphasizing quantifiable outcome variables.

Progress—Overall system performance is being evaluated using appropriate statistical procedures. The evaluation methodology includes, but is not restricted to: 1) the relative proportion of all new SCIs brought into and managed by federally-sponsored Model Systems in a given year, i.e., national capture; 2) average time between injury and system admission, i.e., mean time into system; 3) post-admission death rate, i.e., mortality; 4) post-admission medical complication and surgical procedure rate [i.e., morbidity]; 5) level of postdischarge independence, place of postdischarge residence, vocational outcome, i.e., life function; 6) post-injury hospitalization experience, i.e., length-of-stay and re-admission

experience; and, 7) costs characterized on the basis of appropriate epidemiologic variables to facilitate comparisons between early admission and delayed admission patients.

Preliminary Results—As of June 1987, the national database contained information on 11,374 patients. Overall system performance is being evaluated using appropriate statistical procedures. Additional accomplishments include: the publication and distribution of a new book entitled *Spinal Cord Injury: The Facts and Figures*; presentations at 27 professional meetings; and publication of 25 manuscripts or abstracts in professional journals.

New England Regional Model Spinal Cord Injury System

Murray M. Freed, M.D.

New England Regional Spinal Cord Center, The University Hospital, Boston, MA 02118

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—This project involves the implementation and study of a system of care for the spinal cord injured person. It is based on a coordinated plan beginning at the site of injury, continuing through emergency care, acute medical care, rehabilitation, vocational counseling; and, following discharge—vocational training, housing arrangements, and lifetime medical follow-up. This is done through the organization of a continuum of care by coordinating the contributions of the several medical and co-professional disciplines involved, as well as pertinent state and municipal agencies. Other objectives of the system include the evaluation of the services and cost benefits of such a system of care; developing improved methods and techniques as well as equipment in the treatment of the spinal cord injured individual, and finally, demonstrating programs of community outreach and education for individuals with spinal cord injury in health care maintenance, follow-up, employment, schooling, and other life adjustment activities including recreation.

The project also involves community education for prevention of spinal cord injury as well as education to minimize architectural, social and attitudinal barriers facing the spinal cord injured individual. Programs of education will also be carried out for the benefit of health care groups, agencies, and institutions. The project also addresses itself to

research activities that will improve the life of the spinal cord injured.

Progress—The research activities, both collaborative and intra-institutional, have been organized in areas wherein the gathered information will make significant progress in the pathologic, physiologic psychosocial, and vocational aspects of the spinal cord injured. Intra-institutionally, four areas of investigation will be pursued. In addition, a number of model systems have embarked on an ambitious plan for collaborative research. The New England Center will be involved in six of these collaborative efforts.

Over a 5 year period, it is intended that each research effort will have an N ranging from 350 to 1500. Key investigators of each individual System Project will be the director of the spinal cord injury model system and his designated staff person. Each project has one Model System as the lead organization, with the remaining participants in the role of associate organizations. A cost-effective feature will be the utilization of the already existing facilities and services of the Model Systems and a significant database which is already collected by the National Spinal Cord Injury Data Center. The ultimate collection and data analysis for each project will be done in the lead organization center after input from all of the participating centers.

The collaborative research projects are: 1) Incidence of Respiratory Complications Following Spinal Cord Injury; 2) Long-term Survival and Cause of Death Following Spinal Cord Injury; 3) Recovery of Motor Strength in the Upper Extremities of Quadriplegic Patients after Spinal Cord Injury; 4) The Multi-System Gunshot Wound Study; 5) Spinal Cord Injury Patients with Pre-existing Ankylosing Spondylitis; and, 6) Implications of HMO Reimbursement.

This multicenter effort complements each institution's intramural research efforts for the special investigation, important to the understanding of the physiologic and pathologic impacts resulting from injury to the spinal cord.

Future Plans/Implications—It is anticipated that these efforts will yield new information regarding complications, prevention, early detection of potentially troubling problems and successful management. It is intended that model systems of follow-up, outreach and development of diagnostic techniques and sophisticated evaluation and adaptive equipment as well as collaborative research will further contribute to decrease in costs and improvement in quality of life. Provision of site visits for health agencies, touring groups and representatives of medical institutions seeking information about spinal cord injury

care and concrete methods of organization of spinal cord injury services contribute to the goal.

Publications Resulting from This Research

- Disabled Women's Unmet Needs.** Biener Bergman S, Fertitta L. *Disability Studies Quarterly*, 1986.
- Sexuality and Traumatic Disability.** Ducharme SH, *Handbook of Contemporary Rehabilitation Psychology*, B. Caplan (Ed.), Aspen Publications, Rockville, MD, 1987.
- Developing Training Programs in Sexuality and Disability: A Personal Perspective.** Ducharme SH, *Journal of Sex and Disability* (in press).
- Sexual Functioning in Principles and Practice of Rehabilitation Medicine.** Ducharme SH, Biener Bergman S, Fertitta L. J. DeLisa (Ed.), J.B. Lippincott, Philadelphia, PA (in press).
- Functional Independence in Quadriplegia: Critical Levels.** Welch RD, Lobley SJ, O'Sullivan SB, Freed MM, *Archives of Physical Medicine and Rehabilitation* 67:235-240, 1986.
- Anterior Decompression and Rigid Internal Fixation of Cervical Spine Injuries.** (Abs.) Yablon IG, Ordia J, Freed M, Spatz E, Mortara R, *Paraplegia* 24:49, 1986.
- Justification for the Prescription of Durable Medical Equipment for Spinal Cord Injured Persons.** Donovan WJ, Freed MM, Waters RL, *American Spinal Injury Association*, Chicago, 1986.
- Nutritional Assessment and Estimation of Energy Requirements in Traumatic Quadriplegia.** Lerman RH, Kerrigan MH, Shapiro EA, Jannace PW, Tiller SB, Freed MM, *Proceedings, 13th Scientific Meeting, American Spinal Injury Association*, pp. 304-311, March, 1987.
- The Ascending Cord Syndrome—The Effect of Decompression.** Yablon IG, Ordia J, Spatz E, Reed J, Mortara R, Freed MM, Curtis LA, Biener Bergman S, *Proceedings, 13th Scientific Meeting, American Spinal Injury Association*, pp. 248-253, March, 1987.

Effects of Nutritional Intervention During the Acute Phase of Spinal Cord Injury

C.T. Huang, M.D.

Research and Training Center in Spinal Cord Dysfunction, University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—While the nutritional requirements of the spinal cord injured patient are largely a matter of conjecture, it is reasonable to postulate, in the absence of contradictory data, that there are potential benefits to aggressive nutritional intervention during the early post-injury period. Logic dictates that from a management standpoint it is desirable to minimize negative nitrogen balance while attempting to maintain near-normal weight and other physiologic parameters following trauma. This study is examining the association(s) between an aggressive nutritional intervention program, the prevention of secondary complications, and the preservation of

optimal immune, motor, and psychological function.

Objectives of this study include: 1) conduct of a randomized trial of aggressive nutritional intervention (ANI) for 6 weeks in spinal cord injury (SCI) patients; 2) determination of the effect of ANI on body weight, skin-fold thickness, serum diet-dependent proteins, blood vitamin and zinc levels and hair epilation force; 3) determination of the effect of ANI on incidence of secondary complications; 4) determination of the effect of ANI on muscle function; and, 5) determination of the effect of ANI on T and B lymphocyte numbers, delayed cutaneous hypersensitivity, and serum immunoglobulins.

Progress—Forty-eight SCI patients with neurologically complete, sensory sparing only, or non-functional motor capability type lesions who are between 18 and 60 years of age and less than 60 days post-injury will constitute the study population. Half (24) will have sustained cervical injuries and the remaining patients will have thoracic injuries. Patients with concomitant brain injuries and/or multiple fractures will be excluded.

Patients will be randomly assigned to "treatment" and "control/no treatment" groups. Patients in the treatment group are given aggressive nutritional support for 4 consecutive weeks. During and after this time, comprehensive nutritional, medical complication, muscle mass and function, immune function, and psychological data are collected and analyzed. Appropriate data will be compared for possible identification of association(s) between physiological and psychological findings/responses and ANI.

Preliminary Results—As of November 1986, SCI patients meeting the study's rigorous entry criteria had been enrolled in the project. Provisional data

failed to reveal any meaningful and/or statistically significant differences between the treatment and control groups.

As a result, the aggressive nutritional intervention being provided to each patient in the treatment group by the nutrition team was reviewed in great detail. Based on that review, it was concluded that interventions were not aggressive enough to produce a significant effect on outcome measures being studied (e.g., muscle function, medical complication rates, etc.). Therefore, the ANI methodology was revised to include a randomized, placebo controlled, double-blind study. Patients will be given either 300 mg/day of vitamin C or a placebo capsule. Although opinions differ regarding appropriate vitamin C dosage, 300 mg/day currently is five times the recommended daily allowance (RDA), and therefore is legitimately classified as "aggressive."

Future Plans—During the upcoming year, the new methodology will continue with vitamin C or a placebo being administered daily for 6 weeks.

Clinical Considerations Regarding the Penile Implant in Patients with Spinal Cord Dysfunction

L.K. Lloyd, M.D.

Research & Training Center in Spinal Cord Dysfunction, University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—Erectile dysfunction is prevalent in the spinal cord injury (SCI) population as well as in numerous other males with various forms of spinal cord dysfunction. For patients who do not find alternatives to penile-vaginal intercourse acceptable, the inability to achieve and maintain an erection may be devastating in terms of self-esteem and overall sexual relationship. While surgical and mechanical success rates for penile implants are relatively high, there have been few attempts to rigorously examine SCI patient/partner satisfaction and behavioral changes following implant surgery. Additional study is required to assess these parameters, since clinicians will continue to be confronted with the question of whether the costs and attendant risks (infection/erosion) of such surgery are warranted.

Objectives of this study include: 1) establishment

of objective criteria for inclusion/exclusion of patients as potentially successful implant candidates; 2) development of objective assessment protocols and procedures; 3) determination of the level of sexual satisfaction pre- and post-operatively in patients and their partners; 4) assessment of the sexual behavior pre- and post-operatively in patients and partners; and, 5) documentation of postoperative incidence of mechanical and/or medical complications.

Progress—SCI patients seeking treatment for sexual dysfunction will undergo a comprehensive psychological evaluation that will include administration of the Minnesota Multi-Phasic Personality Inventory (MMPI). Subsequently, they will be assigned randomly to a penile prosthesis or psychological counseling modality for study purposes. MMPI's and

other appropriate psychological profiles will be acquired at 3-month intervals. Ultimately, patients assigned first to the psychological counseling modality will be permitted to proceed with a penile implant after 3 months follow-up.

Preliminary Results—The project is scheduled as a 5-year activity and has been in effect since June 1986. As of November 11, 1986, one patient and his partner have been entered into the project. Initial screening was completed, sexual behavior and satisfaction forms filled out, and the surgical implant

successfully completed. This patient and his partner will soon be eligible for post-surgical follow-up data collection.

A Sexual Health Clinic was initiated and is advertised through the RT Center's newsletter sent to all former patients with spinal cord injury. These announcements have resulted in a steady flow of referrals for sexual information and should continue to provide potential candidates for this project.

Future Plans—The protocol will continue as previously described.

Development of a Prospective Multi-Center Database for Head Injury Utilizing the Data Collection and Analysis Experience of the Model Regional Spinal Cord Injury Care Systems and the National Spinal Cord Injury Statistical Center

T.A. Novack, Ph.D., and C.S. Nepomuceno, M.D.

Research and Training Center in Spinal Cord Dysfunction, University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—From among the millions of head injuries that occur each year, thousands of individuals survive to face significant physical, cognitive, and emotional difficulties associated with recovery. Unlike physical problems, cognitive difficulties do not necessarily diminish with time. At present, it is unclear which head injured persons with residual cognitive deficits are most likely to benefit from extensive professionally-directed care, as there is no consensus as to what the "average" severely head injured person is able to do, given a specific time post-onset.

The development of an evaluation protocol for persons with head injury combines the elements of assessment at fixed intervals, for sufficient lengths of time to derive an adequate assessment of outcome, could produce a pool of information about head injury recovery that might be applied across a variety of rehabilitation settings. Though collaboration exists among several medical centers to develop such a protocol, present data collection procedures are imposing and therefore of questionable use to centers with limited resources. In general, existing data collection projects seem somewhat fragmented, with difficulties arising due to the imposing nature of the data set being used or a lack of similarity of goals across settings.

Objectives of the study are to: 1) survey international rehabilitation centers so as to determine features of their closed head injury data collection and rehabilitation programs, if any; 2) provide summarized instrumentation describing survey findings to rehabilitation centers participating in the survey; 3) develop a pilot data collection protocol based on the findings from the survey; 4) utilize and refine the pilot data collection protocol at this RT Center; 5) employ the refined pilot data collection protocol in other rehabilitation centers in other cities to assess transporability; and, 6) evaluate and assess transportability and utility of the UAB closed head injury data collection protocol.

Progress—Areas of the head injury recovery process to be surveyed will be identified. Data collection/survey instrument(s) will be developed and the addresses of various rehabilitation programs acquired. Survey instruments will be distributed, followed by the re-distribution of instruments to non-responding facilities. Survey responses will be analyzed, and a final summary survey report prepared. Subsequently, a data collection protocol will be developed and staff will be trained in appropriate data collection procedures. Following this, data will be collected at this RT Center. After a thorough

review of data collection activities, a potential expansion site will be selected and contacted. Following completion of all necessary arrangements, data collection will be initiated at other rehabilitation centers.

Preliminary Results—A comprehensive literature review has been completed and a substantial reprint library established. A facility survey instrument was completed and distributed to nearly 2,000 U.S.

hospitals known to have a head injury team unit or head injury rehabilitation unit.

Future Plans—Using this RT Center protocol, a more comprehensive proposal was prepared and submitted to the Centers for Disease Control (CDC) and was approved for funding. Thus, the objectives of the RT Center protocol will be pursued under the CDC grant.

Assessment of Tendon Transfer Surgery in the Tetraplegic Upper Extremity

P. Hunter Peckham, Ph.D.; Michael W. Keith, M.D.; Alvin A. Freehafer, M.D.; Laurel S. Mendelson, M.S.
Case Western Reserve University Rehabilitation Engineering Program, Veterans Administration Medical Center and Metropolitan General/Highland View Hospital, Cleveland, OH 44109

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The purpose of this project is to evaluate the results of tendon transfer surgery in the upper extremity of the C6 level tetraplegic. Studies are designed to measure the voluntary forces produced in the thumb and fingers as a result of tendon transfer, and to identify the muscle firing patterns responsible for these results.

Progress—Voluntary control of lateral pinch and palmar grasp has been restored in the patient with spinal cord injury at the sixth cervical level by transfer of the tendons of voluntarily controlled muscles into the insertions of a paralyzed muscle. Two such procedures are commonly performed in this center: opposition transfers to provide thumb positioning and pinch strength, and finger flexion transfers to provide grasp and a firm surface in which to position the thumb. The two most common muscles transferred for thumb opposition are the extensor carpi radialis longus (ECRL) and pronator teres (PT); the preferred motor for finger flexion is the brachioradialis (BR).

Subjects were divided into two groups. The first group (GI) retained weak C6 function. In these subjects, the BR was transferred to the flexor digitorum profundus (FDP), the ECRL transferred to the abductor pollicis brevis using a graft of the flexor digitorum sublimis of the ring finger, and the posterior head of the deltoid was transferred to the triceps. The second group (GII) had strong C6

function remaining, with the PT transferred for thumb opposition and the BR for finger flexion; the triceps retained voluntary control. Three subjects in each group were evaluated at least one year after surgery. Thumb and finger forces were measured isometrically and muscle firing patterns were measured using electromyography.

Preliminary Results—All subjects were able to voluntarily activate the transferred muscles in order to produce both movement and force in the thumb and fingers. The transferred muscles produced firing patterns which showed adaptation to their new roles. Significant differences in thumb pinch and finger grasp strengths were found between the two subject populations. With the elbow 135 degrees extended and the wrist neutral, the average pinch strengths were 10.6 (s.d. = 2.9) N for GI subjects and 26.4 (s.d. = 7.4) N for the GII subjects. The average grasp strengths were 13.0 (s.d. = 2.1) N and 23.3 (s.d. = 10.3) N. In all positions of the forearm, the subjects with lower C6 function produced greater force than those with weaker C6 function. All subjects showed change in pinch and grasp forces when muscle length was changed by varying the wrist and elbow positions.

New phasic patterns of muscle activity were observed in the transferred muscles. All motors contracted actively to produce motion and force in the digits. Each subject co-contracted an antagonist to elbow flexion (triceps or posterior deltoid) during

activation of the brachioradialis. The weak GI subjects generally contracted all the voluntary muscles in the forearm during attempted grasp and pinch. The strong GII subjects had a greater ability to isolate the firing of a transferred motor from synergistic muscles and from other transferred muscles. In no case did a transferred muscle completely lose its original pattern of firing.

Future Plans/Implications—We are currently extending these evaluation techniques to subjects provided hand control by functional neuromuscular stimulation. These results demonstrate that tendon transfer is effective for restoration of hand function in subjects with high levels (C6) of spinal cord injury. Grasp strength is improved and the subjects are able to activate muscles voluntarily. These procedures may be applied successfully in individuals with higher levels of injury than have previously

been felt to benefit from surgical intervention.

Publications Resulting from This Research

- Postoperative Results of Opponensplasty and Flexor Tendon Transfer in Patients with Spinal Cord Injuries.** Kelly CM, Freehafer AA, Peckham PH, Stroh KP, *Journal of Hand Surgery* 10A(6)(I):891-894, November 1985.
- The Posterior Deltoid to Triceps Transfer: A Clinical and Biomechanical Assessment.** Lacey SH, Wilber RG, Peckham PH, Freehafer AA, *Journal of Hand Surgery* 11A(4):542-547, July 1986.
- The Influence of Muscle Properties in Tendon Transfer.** Peckham PH, Freehafer AA, Keith MW, in *Clinical Mechanics of the Hand*, Paul W. Brand (Ed.), C.V. Mosby Co., St. Louis, MO, 1985.
- Planning Tendon Transfers in Tetraplegia—Cleveland Technique.** Freehafer AA, Kelly CM, Peckham PH, in *Tendon Surgery in the Hand*, J.M. Hunter, L.H. Schneider, E.J. Makin (Eds.), C.V. Mosby Co., St. Louis, MO, 1987.
- The Brachioradialis: Anatomy, Properties, and Value for Tendon Transfer in the Tetraplegic.** Freehafer AA, Peckham PH, Keith MW, Mendelson LS. Accepted for publication, *Journal of Hand Surgery*, 1987.

Psycho-Social Adjustment of Persons with Combined SCI and Closed Head Injury: A Longitudinal Investigation

J.S. Richards, Ph.D.

Research & Training Center in Spinal Cord Dysfunction, University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—Spinal cord injury (SCI) is often the result of rapid deceleration (eg., a motor vehicle crash) and/or a direct impact to the head, neck, or trunk. Therefore, in some cases, an associated closed head injury (CHI) is sustained in addition to the spinal cord injury. While evidence of a concomitant closed head injury is at times quite apparent (coma, CT scan, etc.) at other times “softer” signs of a CHI may not be so apparent and/or may be overlooked.

For example, recent studies of persons who have sustained mild/moderate CHI's—less than 1 hour loss of consciousness (LOC) and/or negative neurologic work-up—have demonstrated that a substantial proportion of such individuals experience debilitating symptoms (memory loss, thinking disturbances, fatigue, irritability) for some period of time after injury, which in turn often leads to an inability to function effectively at work or in school.

In recent years, there has been increasing recognition of the need to closely examine persons with SCI for concomitant CHI. At this RT Center, a

recently completed project focused on determining the coincidence of SCI and CHI via neuropsychological assessment. Similar efforts are underway at several other SCI Centers. However, to our knowledge there have been no prospective studies published to date that have examined adjustment to the home environment, workplace, school, and/or society in general of patients with both CHI and SCI. This project is attempting to do so.

Objectives of the study are to determine: 1) whether persons with concomitant CHI in addition to SCI experience more marital/familial distress postdischarge than a matched group of patients with SCI only; 2) whether persons with concomitant CHI in addition to SCI achieve less progress educationally and/or vocationally postdischarge than a matched group of patients with SCI only; 3) whether persons with concomitant CHI in addition to SCI experience more psychological/behavioral distress postdischarge than a matched group of patients with SCI only; and, 4) whether persons with concomitant CHI

in addition to SCI experience more social maladjustment postdischarge than a matched group of patients with SCI only.

Progress—We will compare the social, vocational, psychological, and familial adjustment, over time, of a cohort of persons with SCI and concomitant CHI and a matched control group of persons with SCI only. The SCI/CHI cohort and the matched SCI controls are being identified. Given the relatively small sample, the variables to be matched are being prioritized. Included in the matching process are: length of time post-injury, neurologic level and extent of lesion, sex, race, and years of education.

A literature review was initiated and completed

for the purpose of identifying existing, well-validated instruments which assess adjustment along social, personal, and vocational dimensions. A mailed questionnaire will be sent to the homes of patients who are scattered across Alabama. The size of the experimental and control groups are expected to be approximately 20-30 persons each.

Future Plans—During the next grant period, the SCI/CHI experimental and the matched SCI control groups will be identified. The assessment instruments, data-collection instruments, and data-collection strategy will be finalized and data collection will begin. Data collection is scheduled to continue through November 1989.

Complications of Cognitive Dysfunction in Spinal Cord Injury ---

Gary Davidoff

Department of Physical Medicine and Rehabilitation, University of Michigan Hospitals, Ann Arbor, MI 48109

Sponsor: *National Institutes of Health*

Purpose—Previous studies of trauma related spinal cord injury patients (SCI) suggest that nearly 50 percent of these patients sustain a concomitant closed head injury (CHI). Early reports suggest that some of these patients demonstrate cognitive deficits within the first year after injury. However, these studies are hampered by several problems, including the lack of controls and the inability to administer screening tests requiring hand function to this population. This study will evaluate neuropsychological deficits in newly injured spinal cord injury patients and relate this to the incidence and severity of medical complications at one year after injury.

Prevalence Study. The incidence and duration of loss of consciousness and traumatic amnesia will be evaluated in newly injured spinal cord injury patients. These patients will undergo a standard battery of neuropsychological testing, which is predominantly motor free, to evaluate deficits in orientation, memory, abstract reasoning and problem solving.

A control group matched for age, sex, level of education, and geographic location will be utilized to develop mental performance ranges on these tests. Premorbid information regarding other factors which may be related to cognitive dysfunction will also be assessed. This study will test the hypothesis that the majority of patients with evidence of cognitive dysfunction have sustained a concurrent CHI.

Medical Morbidity. All patients will be reviewed at one year following discharge from initial rehabilitative care to determine the incidence and severity of medical morbidities associated with SCI. It is expected that patients with associated cognitive dysfunction are at greater risk for the development of medical complications during this 1-year period. Such findings might warrant modification of patient education or length of stay during initial hospitalization as well as the frequency and form of outpatient follow-up for these patients.

Evaluation of Shoulder Position as a Command Control Source

P. Hunter Peckham, Ph.D. and Mark W. Johnson, B.S.

Case Western Reserve University Rehabilitation Engineering Program, Veterans Administration Medical Center and Metropolitan General/Highland View Hospital, Cleveland, OH 44109

Sponsor: National Institutes of Health

Purpose—The purpose of this research is to evaluate the use of shoulder position as a command source for use with functional neuromuscular stimulation (FNS) prosthetic devices by quadriplegic individuals.

Progress—This study was designed to evaluate several of the important aspects of the shoulder movement that defines its performance as a command control source. Three quadriplegic subjects and nine normal subjects were studied. The protraction/retraction and elevation/depression of both shoulders was measured using two dual-axis transducers mounted on the sternum. The experimental procedure included the following areas of study: 1) the range of active shoulder motion; 2) the subject's ability to make incremental shoulder movements; 3) the properties of different types of slow and fast shoulder movements, so that distinguishing characteristics of the movements could be used to derive logical commands; 4) the subject's ability to maintain a desired shoulder position using only proprioceptive feedback; 5) the subject's ability to control horizontal shoulder movements independently from vertical shoulder movements; and 6) the contamination of the shoulder movement signals due to movement of the opposite extremity.

Results—The quadriplegic subjects studied were found to have a considerably poorer active range of shoulder motion than their normal counterparts. Their active protraction and depression were very poor, with their active retraction and elevation being larger, but still approximately half that of the normals. In addition to being weaker than normal, the shoulder elevation had a significant component in the retraction direction, and the retraction had a significant component in the elevation direction, showing a very skewed range that diminishes the separation of the elevation axis from the retraction axis.

These quadriplegic subjects produced a much

lower average number of incremental steps over the vertical range, than the normal subjects. On average, these quadriplegic subjects could produce approximately 11 steps over their vertical range, compared to 37 steps for the normals.

Several parameters were measured for a number of different types of movements, to derive logical command detection algorithms. These movements included quick upward movements, normal step-like movements, and slower ramp-like movements, with movement sizes ranging from small to large. Both rise time and velocity divided by step size were found to be good indicators of the type of movement that a subject was making, whereas velocity was not a good indicator.

The quadriplegic subjects were found to be able to maintain a constant shoulder position to within 1 percent to 5 percent of their shoulder range for trials up to 15 seconds, and within 2 percent to 6 percent for 30 second trials. Most normal subjects were capable of controlling horizontal shoulder movements independently from vertical shoulder movements. However, the quadriplegic subjects tested were found to have poor two-axis control. This is due primarily to the poor horizontal range of these subjects, and the large component of retraction when the subjects elevate their shoulders. The contamination of the shoulder movement signals due to movement of the opposite extremity was also studied. This movement was found to have a magnitude of up to 50 percent of the range of motion. The source of the interference is the mounting of the transducers on the compliant skin. However, the body mounting of transducers is necessary for clinical application.

Future Plans/Implications—We plan to incorporate the command control processing techniques into our patient-portable systems, and test the efficacy of the user's ability to perform without generation of inadvertent command errors.

A Center for Acute Spinal Cord Injury: Epidemiology and Economic Costs of Spinal Cord Trauma

Leon Robertson

Yale University Medical School, New Haven, CT 06510

Sponsor: National Institutes of Health

Purpose—We are continuing to develop a model for the evaluation of the contribution of collateral sprouting of the processes of dorsal root ganglion cells to altered function or recovery following lesions of the spinal cord. We now can manipulate sciatic and saphenous central axons in order to examine, at the light and electron microscopic (EM) levels, alterations in their central terminal fields that occur following lesions. We have concentrated this year on the ultrastructural changes in afferent terminals,

target dendrites and somata, and glia formations that occur in the dorsal horn following rhizotomy, sciatic nerve section, or specific degeneration of sciatic central terminals after injection of the sciatic nerve with pronase. We will now carry out experiments to examine the possible collateral sprouting of saphenous afferents into the sciatic territory following destruction of the sciatic afferents. Documentation of the changes will be carried out with both light and EM analysis.

Body Composition and Nutrition in Spinal Cord Injury

Paul R. Schloerb

University of Rochester Medical Center, Rochester, NY 14642

Sponsor: National Institutes of Health

Purpose—Knowledge of body composition changes and nutritional requirements in spinal cord trauma with paraplegia or quadriplegia is limited. We plan to measure lean body mass (LBM) and total body fat as functions of total body water (TBW) and total body potassium (TBK), under controlled dietary conditions. Total body water will be measured with deuterium oxide (heavy water) and bioimpedance and extracellular fluid will be determined with bromide. When stable, patients will be transported to the 40K Body Counter for measurement of TBK. Studies will be performed shortly after trauma with periodic longitudinal evaluation (40K counting) through rehabilitation. To measure changes in mus-

cle protein turnover and muscle wasting, urinary excretion of the amino acid, 3-Methyl histidine, and urine creatinine will be determined. The effect of spinal cord trauma on bone mineral and soft tissues below the neurologic level of injury will be studied by photon absorptimetry and CT scanning. All of these body composition measurement techniques will be complemented by metabolic balance study periods at intervals to evaluate further the quantitative aspects of losses and gains of soft tissues and bone in spinal cord trauma. From all of these data, optimum protein-calorie nutritional support will be defined.

Neurochemical Correlates of Autonomic Hyperreflexia in an Animal Model

Susan L. Stoddard, Ph.D. and Tony L. Yaksh, Ph.D.

Indiana University School of Medicine, Indianapolis, IN 46202 and Mayo Clinic, Rochester, MN 55905

Sponsor: Paralyzed Veterans of America, Spinal Cord Research Foundation (Proposal NBN-633)

Purpose—Autonomic hyperreflexia (AH), or dysreflexia, is a condition that affects approximately 80 percent of individuals with a high spinal cord tran-

section. This condition involves the mass, reflexive discharge of the sympathetic nervous system, which is isolated from the modulatory control of the central

nervous system when the spinal cord is damaged above approximately the sixth thoracic level. The sympathetic nervous system is part of the autonomic nervous system, which regulates cardiovascular and visceral activities (such as bowel and bladder function). Given these diverse functions, it is not surprising that mass activation of the sympathetic nervous system can give rise to a complex family of symptoms including anxiety, sweating, pounding headaches, nausea, and paroxysmal hypertension. What makes autonomic hyperreflexia puzzling is that in the spinal cord injured person this syndrome may be triggered by a variety of stimuli, including urinary and bowel obstruction or skin irritation. These normally benign stimuli thus can elicit various prominent clinical signs and symptoms. The concomitant hypertension noted above generated by such stimuli may be severe, resulting in seizures, cerebrovascular accidents (strokes) or hemorrhage. Since such consequences can be life-threatening, an understanding of the neurological mechanisms of AH is of importance in controlling and treating the condition. Although AH has been recognized as a clinical syndrome since 1917, and has been well described phenomenologically, the time course of development and the mechanisms underlying this condition have not been systematically investigated.

The aims of our project are to describe the time course of development of AH in an animal model, the spinally-transected cat, and to characterize the associated activity of the adrenal medulla. The adrenal medulla is of particular interest in this syndrome since, as part of the sympathetic nervous system, it is controlled directly by autonomic neurons that originate in the spinal cord. Thus, we believe this organ is involved when the diverse stimuli listed above cause a mass discharge of the sympathetic nervous system. The adrenal medulla synthesizes and secretes a variety of neurochemicals, including catecholamines (noradrenaline, adrenaline, and dopamine) and peptides (such as me-

thionine-enkephalin and neuropeptide Y). All of these neurochemicals have potent direct and indirect cardiovascular effects in addition to other widespread physiological and metabolic actions. We will directly measure the output of these neurochemicals from the adrenal medulla following both somatic and visceral stimuli, and characterize the changes in the stimulus-secretion relationship as a function of time after high spinal cord transection.

Preliminary Results—Preliminary studies initiated in anticipation of this work revealed that the high spinally-transected cat is in fact an excellent model for the study of AH. The chronically-transected animals coped well with hind limb paralysis, developed reflex bladder function, and gained weight. Further, both visceral and somatic stimuli were effective in eliciting AH (defined as an increase in mean arterial blood pressure of at least 30 mm Hg) following chronic, but not acute, transection. This is similar to the clinical situation, in which AH usually develops concurrently with the return of bladder tone. Although it is not possible to translate findings from animal experimentation directly to clinical application, we are optimistic that our experimental paradigm in the spinally-transected cat will lend new insights into the neurochemical bases of AH. In this regard, a major result of our preliminary studies was that AH in the cat is accompanied by a notable activation of the adrenal medulla. This observation is of particular interest since, for obvious reasons, it has not been possible to directly characterize such activity in man.

Future Plans—If these preliminary observations are substantiated by further investigation, our future plans will be to explore the mechanisms of spinal reorganization that permit development of this sympathetic hyperactivity in the spinal cord injured patient.

The Health and Functional Status of Aging SCI Persons: A Feasibility Study Using Cases from Stoke Mandeville Hospital

Gale G. Whiteneck, Ph.D. and Robert R. Menter, M.D.

Craig Hospital, Research and Follow-up Department, Englewood, CO 80110

Sponsor: Paralyzed Veterans of America, Spinal Cord Research Foundation (Proposal NOA-650)

Purpose—The success of modern treatment of persons with spinal cord injury (SCI) can be measured in long-term survival. Presently, the goal of near-normal life expectancy is being met by many survivors of World War II spinal cord injuries. Recent concerns have focused on the impact of aging in this population. The present project is a feasibility study designed to determine if a scientifically valid investigation of aging in persons with spinal cord injury is possible using the records of individuals treated at the National Spinal Injuries Centre (NSIC) in Stoke Mandeville Hospital in England. The NSIC has a 43-year history of providing comprehensive rehabilitation and follow-up to the spinal cord injured, and is an ideal facility at which to conduct this investigation. A variety of resources will be utilized to gather the data necessary for the project. An extensive review of the gerontology literature has provided information from which key study variables have been identified. The medical records of the NSIC will be reviewed and local general

practitioners and district health nurses will be contacted to determine if available information is comprehensive and adequate to investigate the long-term health and functional status of an aging spinal cord injured population.

Future Plans—If the record review provides comprehensive information regarding the health and functional status of spinal cord injured individuals over the years, specific research designs and a major SCI aging research project will be prepared. This will include detailed methodological plans for using the NSIC data for further analyses and developing a protocol for tracking the key health and functional characteristics at facilities like Craig Hospital over the next decade. In addition, it may be determined that personal interviews with persons injured more than 20 years will be necessary in order to obtain information not available from records and other resources.

A Computer Interface for the TIPE Seating Pressure Evaluator

Lincoln A. Jaros, B.S.; Ronald L. Kett, M.S.; Simon P. Levine, Ph.D.

Rehabilitation Engineering Program, Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center, Ann Arbor, MI 48109

Sponsor: Rehabilitation Engineering Program, Department of Physical Medicine and Rehabilitation, University of Michigan

Purpose—Pressure sores are a major problem for individuals who are wheelchair dependent, particularly those with sensory losses. Many researchers have investigated the causes of these pressures sores and have sought methods of preventing them. A project at the University of Michigan is investigating the use of electrical muscle stimulation as a means of preventing pressure sores. Part of this research involves measuring and recording the dynamic forces exerted at the seating interface.

An outgrowth of this work was the development last year of a computer interface to allow an IBM-PC compatible computer to acquire data from a

commercially available pressure sensor pad. The pressure transducer system being used is the Texas Interface Pressure Evaluator (TIPE) pad. The pad consists of a 12 x 12 array of switches within an inflatable pad. Wherever the externally applied pressure exceeds the internal pad pressure the corresponding switch is activated (closed). The TIPE pad is normally connected to a separate display unit which produces a transient visual picture of the pad switch conditions. No provision for the permanent recording of observed data is provided. Clinical evaluations and other experimental protocols require information about pressure behavior to be

recorded over an extended period (e.g., to develop a pressure distribution map for wheelchair cushion evaluation). This recorded data must also be converted to a form which prepares it for computer analysis and hard copy report generation. The following report describes recent changes to the interface developed over the past year.

Progress—The original computer interface was a stand-alone device with its own microprocessor. It was designed to connect to any computer through a standard serial interface. In the interests of simplicity and cost effectiveness, the interface has been completely redesigned. The new version is a single printed circuit board designed to plug directly into the bus of an IBM-PC or PC-compatible. This removes the need for a separate microprocessor and serial communication electronics. The resulting interface is powered by the computer supply and is controlled directly by the main computer. These changes reduce the device chip count and increase the operating speed.

Preliminary Results—Previously developed software which allows sequential recording of the switch on/off configuration over programmable time periods has been modified for the new hardware configuration. In addition, new software has been written to allow the interface to produce a two-dimensional map of interface pressures which can be printed in report form. This is accomplished by slowly releasing air from the pad and recording the pressure at which each individual switch is activated. This test is now being offered clinically from the Rehabilitation Engineering Program for use in evaluating different types of wheelchair cushions. We have recently made this interface available commercially on a limited basis. A small number have been built for other institutions who have a need to study and map seating pressure for clinical or research applications.

Publication Resulting from This Research

A Computer Interface for a Seating Pressure Evaluator. Jaros LA, Kett RL, Levine SP, *Proceedings of the 9th Annual RESNA Conference*, 6:419-421, Minneapolis, MN, June 1986.

Chemical Dependence and Spinal Cord Injury Outcome

Allen W. Heinemann, Ph.D.

Rehabilitation Institute of Chicago, Chicago, IL 60611

Sponsor: *Rehabilitation Institute of Chicago; Spinal Cord Research Foundation; National Institute on Disability and Rehabilitation Research; and National Institute on Alcohol Abuse and Alcoholism*

Purpose—This report describes three currently funded projects. The common goal of these projects is to expand our knowledge about substance use by persons with spinal cord injuries (SCI). Some persons with spinal cord injuries may be at risk for substance abuse, dependence or addiction and, as a consequence, have their rehabilitation outcome profoundly influenced by substance abuse. Early identification of persons with spinal cord injuries who abuse or are addicted to substances, or who are at risk for abuse, should decrease the cost of rehabilitation and improve rehabilitation outcome. Since the annual medical costs for all persons with SCI is estimated at \$1.9 billion, timely and effective intervention for persons with cord injuries who abuse or are at risk for chemical abuse is both humane and cost effective.

Progress—To date, we are well on our way to achieving the objectives of this study. In brief we are seeking to: 1) describe the natural history of substance use among persons with spinal cord injury; 2) quantify the pre-injury prevalence of substance use in 20 categories; 3) validate self-report of substance use with laboratory analysis; 4) quantify the post-injury prevalence of substance use in 20 categories; 5) determine the relationship between pre-injury and post-injury substance use; 6) determine the relationships between personal, medical, social and behavioral characteristics of persons with spinal cord injury and their patterns of substance use both pre- and post-injury; 7) determine the relationship between pre- and post-injury substance use and rehabilitation outcome, including employment; and 8) assess the efficacy of chemical de-

pendence interventions both before and after spinal cord injury.

This prospective project will study the relationship between substance use and rehabilitation outcome in two samples of 100 persons, one sample of persons with recent injuries, and one sample of community residents whose injuries occurred more than one year ago.

A total of 103 Rehabilitation Institute of Chicago (RIC) inpatients who met the following admission criteria were recruited for the study: traumatic SCI within the last 12 months; between age 13 and 65, inclusive; no clinically significant head trauma, defined as no post-traumatic amnesia exceeding 24 hours; and informed consent to participate (parental consent when appropriate).

A total of 101 community residents have consented to participate who were recruited through the Northern Illinois Chapter of the National Spinal Cord Injury Association (NSCIA) and Access Living of Metropolitan Chicago (Access Living).

Our procedures for recruiting the inpatient sample included reviewing a record of daily admissions from the admitting department at RIC. This record contained patient names, admission dates, identification numbers, diagnoses, and attending physicians' names. The attending physician for each patient was contacted between the second and fourth week following admission to request permission to contact patients. Each patient was contacted only after permission was obtained. A meeting time was arranged to fully describe the purpose and procedures of the study. Ample time was provided for decision making because of initial hesitation in agreeing to participate. This procedure allowed us to recruit 67 percent of the eligible inpatients.

Preliminary Results—The initial evaluation included assessment of: biographic information, social status, depression, self-esteem, and activity patterns. The Substance Use Inventory was used to obtain data regarding all substances used prior to SCI, while the Substance Use Questionnaire was administered for all substances used during the six months prior to SCI. Some participants needed additional time and assistance to complete the interviews; shorter interviews were arranged as necessary to avoid fatigue and to maximize reliability. The interviewer provided physical assistance as required to complete the instruments. In some cases this included reading all items and recording responses. After each par-

ticipant was discharged from RIC, the medical record was reviewed for duration of stay, total charges, and prescribed medications administered and received.

Letters were sent to community members which explained the purpose of the project and solicited participation. A return-addressed, stamped postcard was enclosed so that individuals could contact the investigators requesting more information about the study or to volunteer. An interview was set via telephone and informed consent was obtained from persons agreeing to participate. The age, sex, race and injury level of all eligible persons who chose not to participate was recorded so that the representativeness of the sample can be assessed. Of the 237 persons contacted, 118, or 50 percent agreed to participate.

Future Plans/Implications—Initial, 6-, 18-, 30-, and 42-month post-injury evaluations are planned for the recent injury group; as planned, all of the initial and 6-month post-injury evaluations are complete. In addition, all community residents have been evaluated once; a one- and two-year follow-up is planned. All five instruments are administered at these re-evaluations. The information obtained at each assessment will be current for social status, depression, disability acceptance, and activity pattern. Substance use histories will cover the period of time since the last interview. Data analysis is underway to address the objectives listed above.

Publications Resulting from This Research

Alcohol Use and Activity Patterns Following Spinal Cord Injury. Heinemann A, Keen M, Schnoll S, Adair W, Paper presented at the *12th Annual Meeting of the American Spinal Injury Association*, 1986.

Alcohol Use and Activity Patterns Following Spinal Cord Injury. Heinemann A, Keen M, Adair W, Schnoll S, Paper presented at the *94th Annual Convention of the American Psychological Association*, Washington, DC, 1986.

Alcohol Use and Activity Patterns in Long-Term Spinal Cord Injury Outcome. Heinemann A, Keen M, Schnoll S, Paper presented at the *13th Annual Meeting of the American Spinal Injury Association*, Boston, MA, 1987.

Substance Use by Persons with Recent Spinal Cord Injuries. Heinemann A, Keen M, Mamott B, Schnoll S, Paper presented at the *95th Annual Convention of the American Psychological Association*, New York, NY, 1987.

Toxicology Screening in Acute Spinal Cord Injury. Heinemann A, Schnoll S, Brandt M, Maltz R, Keen M, Paper presented at the *95th Annual Convention of the American Psychological Association*, New York, NY, 1987.

Prevalence of Substance Use in Persons with Spinal Cord Injury. Heinemann A, Armstrong A, Asher M, Keen M, Paper presented at the *64th Annual Session of the American Congress of Rehabilitation Medicine*, Orlando, FL, 1987.

Outcome Studies Pertinent to the National Model Spinal Cord Injury System

M. Fuhrer, Ph.D.; R.E. Carter, M.D.; W.H. Donovan, M.D.

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *Rehabilitation Research and Training Center on Spinal Cord Dysfunction; National Institute on Disability and Rehabilitation Research*

Purpose—This project encompasses three studies, two retrospective and one prospective, aimed at providing additional evidence about the effectiveness of the National Model Spinal Cord Injury System Project administered previously by RSA and currently by the National Institute on Disability and Rehabilitation Research.

The two retrospective studies capitalize upon existence of the common database established by the national systems. One study is an attempt to demonstrate that the highly advanced system of care practiced at the Royal Perth Hospital in Australia results in better patient outcomes than obtained in the less advanced care systems in the United States. The second study is concerned with documenting post-rehabilitation outcomes for quadriplegic patients who, at discharge from inpatient rehabilitation, require ventilatory assistance.

In the prospective study, the outcomes of two groups of patients are compared. One consists of patients whose acute and rehabilitation care was provided by the Texas South Central Regional Spinal Cord Injury (T/SCRSCI) System. It is comprised of four acute care hospitals in the Houston-Galveston area and The Institute for Rehabilitation and Research (TIRR) as the rehabilitation setting. The second group consists of patients who were discharged from the same four acute care hospitals but who did not receive rehabilitation services at TIRR.

Data for TIRR patients are being obtained in a companion project entitled, "Assessment, Development, and Clinical Application of Strategies to Coordinate Services for Spinal Cord Injured Clients After Discharge." Data for non-TIRR patients are being obtained during home interviews using an adapted form of the interview used in the companion project.

Progress—During the project's first year, the U.S.-Australian systems study directed by Dr. William

Donovan was completed, and an article was published in *Paraplegia*, 22:282-290, 1984. In that study, one data set reflected experience with 65 consecutively admitted patients whose care during 1979 and 1980 occurred in the spinal cord unit at the Royal Perth Rehabilitation Hospital in Perth, Western Australia. A second data set pertained to 1606 U.S. patients who had been cared for in one of the regional systems during the same year.

Preliminary Results—The results indicate that decubitus ulcers, atelectasis, pneumonia, pulmonary emboli, ulcers of the gastrointestinal tract, and heterotopic ossification all occurred more frequently in the U.S. group. The difference was particularly marked for decubitus ulcers and urinary tract infections. These outcomes demonstrate that the sooner spinal cord injured patients are referred to a center capable of meeting all their needs, the less likely it is that they will develop complications that slow rehabilitation progress.

Results describing post-rehabilitation outcomes for ventilatory dependent quadriplegics have been published in 1987 in the *Archives of Physical Medicine and Rehabilitation*. Compared with ventilator independent quadriplegics, ventilator dependent individuals had a longer duration of hospitalization, less self-care capability, more hours per week of hired attendant care, and more hours of actual physical assistance per day. The groups did not differ significantly in terms of duration of inpatient rehabilitation, duration of rehospitalization, and vocational or prevocational status at follow-up.

Future Plans/Implications—The prospective study comparing outcomes for system and non-system patients is continuing. Complete data are available currently for 150 system patients and 30 non-system ones.

An Implantable Sensor for Two-Degree-of-Freedom Position Transduction

P. Hunter Peckham, Ph.D.; Michael W. Keith, M.D.; Jorge Letechipia, M.Sc.

Case Western Reserve University Rehabilitation Engineering Program, Veterans Administration Medical Center and Metropolitan General/Highland View Hospital, Cleveland, OH 44109

Sponsor: *Paralyzed Veterans of America, Spinal Cord Research Foundation*

Purpose—The purpose of this project is to develop a sensor for acquiring command control information of joint position. The sensor is to be surgically implantable, and be used to transduce position of two-degree-of-freedom joints, such as the sternoclavicular and the wrist.

Progress—Evaluation of different transduction techniques as design alternatives has been completed. Inductive displacement gauges, pressure sensors, bubble sensors, capacitive transducers, electromagnetic position transducers, inductive-type transducers, potentiometric devices, ultrasonic detection, tendon displacement, optic fibers and magnetic flux sensors (Hall Effect sensors) were evaluated, and their applicability and characteristics compared.

Preliminary Results—The results of these studies show that a Hall Effect device, properly positioned and aligned, could be used to meet the transduction requirements of a two-degree-of-freedom joint.

The design that we have chosen is composed of three separate elements: the sensors, their signal conditioning circuitry, and a permanent magnet. The magnet will be implanted in one side of the joint while the sensors and circuitry will be implanted in the other side of the selected joint. The transducer

we have designed consists of two pairs of sensors, located at 90 degrees with respect to each other and the magnet. Each pair of sensors (X and Y) is connected differentially. Thus two signals are generated, one indicating the angular displacement in X, while the other corresponding to the Y angular displacement of the magnet. A ball and socket mechanism was used to simulate the joint configuration. Preliminary results obtained earlier with a non-implantable transducer, built and operating under the same design principle, provided us with an adequate command control source to use with our clinical, upper extremity FES program.

Future Plans/Implications—Future plans include further characterization and packaging of the transducer elements. *In vitro* and *in vivo* experiments will be conducted by externally powering the device. At the completion of this project, we expect to have determined the viability of the Hall Effect transducer system as a source of joint position information. We believe that the availability of an easily obtainable, two-degree-of-freedom proportional command control source would be of interest and use to the rehabilitation community as an interface with neuroprostheses as well as a variety of orthotic/prosthetic aids and assistive devices in general.

B. Medical Treatment

Early Detection of Pressure Sores by Means of Biomedical Indicators

George Van B. Cochran, M.D.

Veterans Administration Medical Center, Castle Point, NY 12511 and Orthopaedic Engineering and Research Center, Helen Hayes Hospital, West Haverstraw, NY

Sponsor: *VA Rehabilitation Research and Development Service (Project #XB212-2RA)*

Purpose—Decubitus ulcers represent a severe problem for spinal cord injured patients. If a reliable and

practical clinical method of early detection of decubiti could be developed, it is probable that in

many cases, with suitable medical intervention, frank tissue breakdown could be reversed or at least limited in its severity. Various techniques for early detection of decubiti have been investigated to identify changes in mechanical, physical or physiological properties of compromised tissues. None to date have yielded a reliable and clinically practical means to detect early tissue damage.

We are currently conducting a study to investigate changes in the acoustic properties of tissues associated with pressure-induced damage. This proposal addresses a need for a parallel effort to develop a simple to use, inexpensive screening technique for early tissue damage. Patients whose tissue status is unsatisfactory would then be candidates for imaging techniques costing more to operate, and available at a central location under the supervision of skilled, specialist operators. In themselves, the imaging techniques are too complex for screening.

Current clinical practice for early detection of decubiti relies upon frequent inspection of skin color. Persistent red areas are often classified "stage I decubiti" and appropriate clinical measures taken. Several difficulties and limitations are, however, experienced with this highly subjective technique. Firstly, it is important for the clinician (or patient) to differentiate between persistent redness and the normal, healthy (short-term) redness of reactive hyperemia. Secondly, in the more advanced stages of decubitus formation, the area becomes ischemic and cyanotic with often only a margin of redness. Thirdly, all skin color changes associated with the early onset of decubiti are difficult to detect in nonwhite patients.

Sweat glands are richly endowed with a capillary blood supply which carries biochemicals whose concentrations may serve as indicators for decubitus formation. Associated with the inflammatory response, elevated levels of mediators such as histamine in the blood stream are well known. Limited evidence from basic research on the chemistry of sweat suggests that histamine may be transported

through the sweat gland membrane. In principal, it would therefore seem feasible to use sweat as a vehicle for monitoring localized histamine production and hence inflammation, non-invasively.

Using an appropriate technique, an area of local inflammation will be induced in a group of able-bodied subjects using a technique similar to the allergy "patch test" and sweat collected at that site. The concentration of histamine in the sweat sample will be measured and compared with sweat collected from a control site. Evidence to confirm that histamine readily diffuses into sweat from capillary blood and surrounding tissues will be sought. A clinical study will then be undertaken analyzing sweat from a group of spinal injured patients with clearly defined localized persistent redness of the skin. Sweating will be induced locally using iontophoresis of pilocarpine nitrate in the erythematous tissues and also from a control site of normal healthy appearance. The hypothesis for this study proposes that there will be marked elevation of histamine in sweat from the erythematous site compared with the control. If positive, this result would form the basis for establishing a routine test for tissue status that could be undertaken routinely by a hospital biochemistry laboratory.

An adjunct to local analysis of biochemical changes associated with tissue breakdown is the possible increase in biochemical factors in the systemic blood supply. A study by others of CPK levels in elderly people who have fallen and lain injured for prolonged periods also indicates that this test can be used to selectively screen for skeletal muscle damage. In preliminary work using a pig model we have found a significant and sustained increase in CPK associated with pressure damage to tissue. We propose to confirm that CPK can be used as a systemic indicator for early detection of decubiti through controlled experiments using our established porcine model. In addition, CPK may help establish improved tissue tolerance curves for sustained pressure.

A Feasibility Study on Detection of Impending Pressure Sores Using Ultrasound

George Van B. Cochran, M.D., M.Sc.D., and M.P. Kadaba, Ph.D.

Orthopaedic Engineering and Research Center, Helen Hayes Hospital, W. Haverstraw, NY 10993; and Surgical Research Service, Veterans Administration Medical Center, Castle Point, NY 12511

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Pressure sores are a major complication for spinal cord injured and certain other disabled persons. Frequently, these areas of tissue breakdown begin deep in pressure-sensitive areas of muscle tissue and cannot be detected clinically until the process has become irreversible. The objective of our current study is to evaluate the feasibility of using ultrasonic techniques (measurements of attenuation and integrated backscatter) for assessing the state of deep muscle tissues with respect to early changes signaling the incipient development of muscle necrosis.

The proposed research will approach this problem by means of our established experimental model in pigs. Tissue damage in the animals is created by applying a constant force, over a period of hours, through specially shaped pneumatic indentors. This technique is being employed to create a known degree of tissue damage on which specific acoustic parameters can be measured for comparison to normal.

Progress—A three-dimensional precision scanning system, driven by stepper motors under the control of a computer, was developed for positioning the ultrasonic transducer over a tissue region of interest. Three groups of 4 Yorkshire pigs were indented for six hours at an indentation pressure of 700mm of Hg (13.9 psi), using 2cm diameter indentors. The indentation site chosen for these experiments was the tissue region over the mid-back region. The animals in the first group were sacrificed 7 days post-indentation, the second group 14 hours post-

indentation, and the third group 21 days post-indentation. Backscattered signals from tissue regions of interest were recorded, *in vivo*, before and after indentation and, *in vitro*, from excised tissue specimen. Data were recorded at 25 locations from each site of indentation and corresponding normal region. A focused 5 mHz, broad base ultrasonic transducer was used in all the measurements. To date, calculation of the slope of attenuation and integrated backscatter has been completed only on the *in vitro* data from the first group of animals.

Results—Preliminary results show that in the first group, the integrated backscatter was significantly increased in the damaged region ($-33.8 \pm 3.1\text{dB}$) compared to normal region ($-46.3 \pm 4\text{dB}$). However, the slope of the attenuation coefficient of damaged region (0.096 ± 0.023 nepers/cm/mHz) was not significantly different from that of normal tissue (0.099 ± 0.026 nepers/cm/mHz). Further, the standard deviation of attenuation measurement was large, confirming the earlier findings that the skeletal muscle tissue is highly inhomogeneous. Data analysis from the other two groups of animals is currently under way.

Future Plans/Implications—If this feasibility study is successful, it will lead to a clinically usable ultrasonic scanning test that can warn of impending pressure sores at the preclinical stage; in time to take corrective action to permit healing before tissue necrosis occurs.

A New Technique in the Assessment and Treatment of Autonomic Dysreflexia

Kenneth Lehmann, M.D.

Veterans Administration Medical Center, Long Beach, CA 90822

Sponsor: VA Rehabilitation Research and Development Service (Project #SCI-B468)

Purpose—Despite the marked improvement in survival over the past few decades, spinal cord injury

(SCI) remains a devastating disease. Understandably, most efforts in rehabilitation have been directed

at the profound motor disabilities accompanying spinal injury. However, the autonomic nervous system may be compromised as well. As the cardiovascular system is highly dependent upon autonomic influences, it is logical that SCI might interfere with the complex mechanisms involved in cardiovascular rehabilitation. In work recently completed by the principle investigator, severe acute injury to the cervical spinal cord in man has been shown to be regularly accompanied by alterations in cardiovascular function, including bradyarrhythmias, asystole, marked hypotension, supraventricular tachyarrhythmias, and atrioventricular block. In addition, these individuals also experienced a statistically significant increase in primary cardiac arrests that often proved fatal. These abnormalities were not found in patients with injuries of the thoracic or lumbar cord. Evidence is presented that implicates an acute autonomic imbalance imposed upon the heart and vasculature by a cervical cord injury as the mechanism responsible for these abnormalities.

Interestingly, these cardiovascular disturbances in all instances resolved spontaneously 2 to 6 weeks after injury. Though this adaptive response is obviously beneficial, the chronic stage of cervical SCI is marked by its own set of cardiovascular abnormalities. Chief among these is autonomic dysreflexia. This condition, common to most quadriplegics, is characterized by transient episodes of profound hypertension, diaphoresis, bradycardia and piloerection, along with flushing above and vasoconstriction below the level of injury. Autonomic dysreflexia has presented a major obstacle in the rehabilitative program of many SCI patients. To date, the mechanism of this apparent mass sympathetic reflex has not been established and no satisfactory treatment has been discovered.

It is the purpose of this study to develop a method of subjectively and objectively quantifying the frequency and severity of spontaneous autonomic dysreflexia in patients at risk, to institute procedures

designed to induce autonomic dysreflexia and orthostatic hypotension in patients in a controlled laboratory setting with quantitative assessment of the response, and to perform a randomized, double blind, placebo controlled crossover trial to evaluate the efficacy of transdermal clonidine for the treatment of these disorders.

The frequency and severity of autonomic dysreflexia during routine activity can be reliably and reproducibly ascertained through the use of ambulatory blood pressure monitoring. Symptoms of autonomic dysreflexia are regularly accompanied by transient elevations of systolic blood pressure, but many episodes of brief hypertension go clinically unrecognized. Autonomic dysreflexia and orthostatic hypotension can be safely induced in humans in the laboratory setting, with accurate quantitative assessment possible using noninvasive techniques. Transdermal clonidine is a useful prophylactic agent for the abatement of both clinical and subclinical episodes of autonomic dysreflexia without exacerbating pre-existent orthostatic hypotension. Specific objectives of this project:

- 1) To employ 24-hour ambulatory blood pressure monitoring in symptomatic patients with high-level spinal cord injury to ascertain short-term systolic pressure variability, and quantitate transient hypertensive episodes as an index of autonomic dysreflexia.
- 2) To execute a randomized, double-blind, placebo-controlled crossover trial investigating the utility of transdermal clonidine in the treatment of autonomic dysreflexia and orthostatic hypotension during routine ambulation.
- 3) To provoke dysreflexia and orthostasis in a controlled setting with noninvasive hemodynamic monitoring during randomized transdermal therapy with clonidine or placebo.
- 4) To study the neurohormonal response to dysreflexia and hypotension and the role of clonidine in the mediation of this response.

A Pilot Study on Alterations in Blood Rheology in Spinal Cord Injured Patients

A.H. Sacks, Ph.D.; Arundhati Perakash, M.D.; Inder Perakash, M.D.
Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service (Pilot Proposal #B937-PA)

Purpose—Rheology is the study of flow and deformation of materials. Blood is considered to be a

rheological material because it can exhibit both liquid and solid behavior, depending upon the nature

and magnitude of the applied forces. Because of the importance of red cell rigidity and the viscous behavior of blood in venous thrombosis and in the initiation of microcirculatory compromise, and the relationship of the latter to the initiation of pressure sores, it is proposed that a pilot project be undertaken to study blood rheology of spinal cord injured subjects in comparison with that of normal controls without spinal cord injury. The necessary space and most of the instrumentation are currently available at the Spinal Cord Injury Center and the Laboratory Service of the VA Medical Center, Palo Alto.

Pressure sores and deep vein thrombosis are major problems in patients with spinal cord injury. Since observations in patients with other diseases have

shown that increases in blood viscosity and red cell rigidity are associated with tissue necrosis and/or thrombosis, there is a possibility that these factors may be of significance in the causation of pressure sores and/or deep vein thrombosis in patients with spinal cord injury. Both increased blood viscosity and red cell rigidity can at present be treated by drugs. We propose to perform a pilot study to determine whether there is indeed an increase in blood viscosity and/or red cell rigidity in patients with spinal cord injury in comparison with normal subjects without spinal cord injury. If this pilot study shows encouraging results, then a subsequent full-scale investigation will be proposed as a Merit Review project.

Sacral Nerve Stimulation for Neurogenic Bladder Management in Spinal Dog

James S. Walter, Ph.D.; Charles J. Robinson, D.Sc.; John S. Wheeler, M.D.; Robert D. Wurster, Ph.D.;
Talat Khan, Ph.D.; J. Bolam; J. Stein; H. Doktycz; M. D'Astice

Hines VA Hospital, Rehabilitation Research and Development Center, Hines, IL and Loyola Medical Center,
Department of Urology and Physiology, Maywood, IL 60611

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The spinal cord injured patient does not have control of bladder voiding. This results in many problems including urinary incontinence, urinary infection, and high bladder pressures which can result in urological problems. Renal pathology secondary to these bladder changes continues to be a cause of morbidity in the spinal cord injured patient.

Sacral stimulation has been effective in clinical trials using cuff electrodes on sacral nerve roots within the sacral canals (Brindley et al., *J Neurol Neurosurg and Psychiatry* 49:1104, 1986). However, invasive surgical implantation procedures, including laminectomy and opening the dura for implanting nerve cuff electrodes, have been required. Less invasive methods are needed. In preclinical trials, we are evaluating two less invasive methods of sacral stimulation for bladder management, both surface electrodes over sacral foramina and epidural electrodes in the sacral canal implanted via a modified percutaneous procedure. Criteria for an effective method include optimum electrode arrangements and stimulating parameters in terms of pressure and voiding volume, number of stimulations to employ the bladder and residual volume.

Less invasive methods of sacral stimulation can be used for bladder management. Sacral stimulation

with either surface or implanted needle electrodes can effectively stimulate bladder motor fibers, induce bladder contraction and voiding. Stimulation can be safely applied.

Progress—Previously, we managed the bladders of one chronic spinal male and female dog for over 2 years using similar procedures to those described here (Tang and Walter, *Neurourol and Urodyn* 3:43-50, 1984). The current results concern using less invasive epidural needle electrodes (PISCES SIGMA and QUAD, Medtronic) and surface electrodes in spinal animals.

Four evaluations are being conducted to meet our goal of bladder management with sacral stimulation in the chronic spinal dog:

1) Establish a model: conduct T8-9 spinal transection and implantation of epidural sacral electrodes in male dogs. Instrument chronic spinal dogs for recording bladder pressure, colon pressure, pelvic floor electromyography and volume voided. Maintain animals in good health according to NIH and AAALAC guidelines.

2) Determine optimum electrode arrangements: A single monopolar electrode on the sacral midline is a good arrangement for implanted electrodes and

surface electrodes over the S2 sacral foramina appear to be optimal.

3) Determine optimum stimulating parameters: One to three seconds bursts of 10 pps stimulation at currents of 1 to 2.5 mA for implanted electrodes and 25 to 40 mA for surface electrodes is effective.

4) Determine urodynamic responses: After the first three weeks of stimulation when bladder re-

flexes had returned, voiding was effective with 10 to 100 ml following each stimulation, and residual volume after repeated stimulation was less than 50 ml.

Papers will be published documenting the above results and additional observations on urethral mechanisms in the chronic spinal dog.

Inhibition of the Hyperreflexic Bladder: Preclinical Trials

James S. Walter, Ph.D.; Charles J. Robinson, D.Sc.; John S. Wheeler, M.D.; Robert D. Wurster, Ph.D.; Talat Khan, Ph.D.

Hines Veterans Administration Hospital, Rehabilitation Research and Development Center, Hines, IL and Loyola Medical Center, Department of Urology and Physiology, Maywood, IL 60611

Sponsor: VA Hospital, Rehabilitation R&D Center Core Funds

Purpose—Spastic bladder contractions in the spinal cord injured patient result in incontinence and high bladder pressure. The spinal cord injured patient needs to be able to prevent unwanted bladder contractions.

Sacral stimulation has been effective in clinical trials for inhibition of the bladder using cuff electrodes on sacral nerve roots within the sacral canals (Brindley et al., *J Neurol Neurosurg and Psychiatry* 49:1104, 1986). However, invasive surgical implantation procedures, including laminectomy and entry inside the dura for implanting nerve cuff electrodes, were required. Less invasive electrode implantation methods are needed. In preclinical trials, two methods of sacral stimulation are being evaluated: surface electrodes over sacral foramina and epidural electrodes in the sacral canal implanted via a modified percutaneous procedure. Optimum electrode arrangements and stimulating parameters will be determined in chronic spinal animals. The criteria for bladder inhibition will be prevention or reduction of bladder contractions induced by cystometry and rubbing the perineum.

Less invasive methods of sacral stimulation can be used for bladder inhibition. Sacral stimulation with either surface or implanted needle electrodes

can effectively stimulate bladder motor fibers, inhibit bladder contractions, and promote continence.

Progress—We have preliminary observations on inhibition of bladder contraction using two techniques of sacral stimulation, low frequency (2 to 20 pps), low current, and high frequency (200 to 4000 pps) high current, in chronic spinal dogs. We are switching to a spinal cat model because this animal has been shown to have urodynamic measures similar to the SCI patient (Galeano et al., *Neurourol and Urodyn* 5:45-63, 1986).

Four evaluations are being conducted to show bladder inhibition with sacral stimulation in the spinal animal. These are as follows. 1) Establish a model: conduct T1-2 spinal transection and implantation of epidural sacral electrodes in male cats. Instrument chronic spinal cats with a suprapubic catheter, and record colon pressure, pelvic floor electromyography and volume voided. Maintain animals in good health according to NIH and AAALAC guide lines. 2) Determine optimum electrode arrangements and stimulating parameters for inhibition of induced bladder contractions. 3) Determine if hyperreflexic bladder problems are improved with chronic stimulation for bladder inhibition.

Effect of Intermittent Catheterization on Renal Stone Formation in Spinal Cord Injury Patients

J. R. Burns, M.D.

Research and Training Center in Spinal Cord Dysfunction, University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—Because spinal cord injury (SCI) patients commonly experience alterations in calcium metabolism (hypercalciuria) which may persist for many months after injury, it is necessary to determine how, if at all, intermittent catheterization in the presence of hypercalciuria affects the risk of urinary tract stone formation. This study seeks to examine the effects of intermittent catheterization and determine the significance of hypercalciuria in SCI patients.

Progress—The study population consists of patients with neurologically complete spinal cord injuries who are identified and entered into the study within 1 week of injury. Twenty-four-hour urine specimens are collected at admission and twice weekly thereafter until the patient is discharged. Serum calcium is measured. Urine pH and species concentration measurements are obtained at regular intervals. Relative supersaturation of the urine with respect to calcium oxalate and calcium phosphate is determined. Activity product and the formation product ratio of brushite is determined for each specimen. All data are analyzed statistically. Nine patients were followed for at least 5 weeks.

Results—Serum calcium was measured in all patients at entry. Six patients had hypercalciuria on at least one occasion with increased calcium detected in the

first 24-hour urine sample. Urinary calcium excretion returned to normal within 8 weeks of injury. Urinary oxalate excretion values fluctuated greatly because many patients received large doses of intravenous vitamins during the first few weeks after injury.

It was postulated that urinary supersaturation of calcium oxalate and possibly brushite would increase significantly when SCI patients were started on ICP (intermittent catheterization program) because urine volume would decline while urinary calcium excretion remained elevated. Indeed, in this series, urinary volume did decline. The average urinary output was 1959 ml/24 hours before ICP and 1280 ml/24 hours after ICP. However, the pattern of urinary calcium excretion differed from our expectations. Calcium excretion returned to normal in all patients within 8 weeks of injury. Since oxalate excretion varies little in normal individuals, the same is probably true for SCI patients.

Future Plans/Implications—It appears worthwhile to measure urinary calcium excretion prior to starting an ICP. If urinary calcium excretion is markedly elevated, ICP should be postponed for several weeks. Since patients are generally normocalciuric within 8 weeks of injury, such postponements can be of reasonably short duration.

Incidence, Characteristics, and Clinical Significance of Anemia in Patients with Spinal Cord Dysfunction

C.T. Huang, M.D.

Research and Training Center in Spinal Cord Dysfunction, University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—Anemia commonly develops within the first 6 months following spinal cord injury (SCI), even in the absence of detectable blood loss. Whether anemia is due to stress, inadequate nutrition, blood

loss, depressed red blood cell (RBC) production, or increased RBC destruction has not been determined. Anemia may be an important factor in the development of secondary complications. It may also

delay or prolong the rehabilitation program. Thus, finding the cause of anemia in this population is a requisite to its prevention.

This study seeks to: 1) determine those epidemiologic and/or demographic variables affecting the duration and/or severity of anemia; 2) determine the natural history of changes in the hematologic profile of SCI patients; 3) establish the natural history of RBC kinetics after SCI; and, 4) determine whether alterations in nutritional profile are associated with the incidence, duration, and/or severity of post-injury anemia.

Progress—A series of neurologically complete quadriplegics (who have not received blood transfusions following their SCI) constitutes the study population. Demographic characteristics and the hematologic correlates of the population are being documented, as are basic hematologic profiles. Ferrokinetic studies are being performed. Nutritional profiles and their hematologic correlates are established. Erythropoietin quantitative assays are being performed. All data will be analyzed utilizing appropriate statistical techniques.

Preliminary Results—The project was initiated in June 1984. As of November 1986, 23 patients had

been entered into the study population. All 23 patients were found to have mild normocytic and normochromic anemia, a profile that is characteristic of patients with chronic disorders. Anemia was found as much as 7 weeks post-injury. During the same period, red cell mass was almost always low ($x = 1592.6$ mls) and plasma volume was almost always high ($x = 3093.7$ mls); yet total blood volume remained constant.

Total body hematocrit count measured by the isotopic method was always lower than hematocrit values from peripheral blood measured by the regular clinical laboratory. Therefore, it is concluded the true hematocrit should be based on isotopic measurement.

Since both erythropoietin and reticulocyte count were within normal limits, it is unlikely the anemia was caused by either the red stem cell maturation process in the bone marrow or the release of mature red cells into the peripheral blood from the bone marrow. However, additional iron turnover and red cell survival data are needed before any firm conclusions can be drawn.

Future Plans—Patients will continue to be entered in the protocol until 48 subjects have been enrolled. Preliminary data analysis began in the fall of 1987.

Pain Secondary to Gunshot Wound During the Initial Rehabilitation Process in Spinal Cord Injury Patients

J. S. Richards, Ph.D.

Research and Training Center in Spinal Cord Dysfunction, University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—Surgical management of gunshot-related spinal cord injury (SCI) is controversial. There is concern that routine decompression laminectomies (in which the bullet and/or bullet fragments are removed) may aggravate the patient's prognosis rather than improve it.

Removal of the bullet tends to be a standard practice whether or not its presence represents a life-threatening situation. It is widely accepted that removal reduces the intensity of associated pain later in life. However, there is virtually nothing in the literature supporting this contention. By contrast, other clinicians believe laminectomy may

contribute to general instability of the vertebral column in addition to being partially responsible for some reported pain. Finally, there is a clinical impression that pain occurring secondary to a gunshot wound may differ in character from that occurring secondary to SCI resulting from other causes. This study is intended to help clinicians understand intractable pain following SCI, and also to verify or refute the efficacy and desirability of decompression laminectomy and bullet removal after SCI.

Specifically, this study seeks to: 1) determine whether the incidence of pain reported in GSW/SCI patients is significantly different than the incidence

in patients whose SCIs result from other etiologies; 2) characterize the incidence of pain reported by GSW/SCI patients epidemiologically and demographically; 3) determine the relationship between incidence of pain in GSW/SCI patients and surgical removal of the bullet; and, 4) determine, prospectively, the incidence of pain in GSW/SCI patients with or without decompression laminectomy.

Progress—This is a two-phase, prospective study. In Phase 1, pain data are collected on all SCI admissions (except those excluded because of overlying psychosis or senility) on a weekly basis from time of admission to first definitive discharge, with pain behavior changes being assessed over time. Data are evaluated with regard to epidemiologic and demographic characteristics of the population. GSW/SCI patient data are studied to determine absence or presence/location of the bullet or bullet fragment(s). If surgically removed before this phase, the pre-surgical location is documented. Pain history is documented and analyzed statistically. Patient outcome will be evaluated.

Preliminary Results—As of November 1986, the

project had enrolled 15 SCI patients who had the bullet or bullet fragment removed from the spinal canal, 10 SCI patients in whom the bullet or bullet fragment remains in the canal, 9 SCI patients in whom the bullet or bullet fragment remains present elsewhere, and 4 SCI patients in whom the bullet or bullet fragment was removed from a site other than the spinal canal. Approximately 30 SCI patients without gunshot wounds have also been entered into the study.

It can be tentatively concluded that removing the bullet does not always prevent pain, and furthermore, leaving the bullet in the canal does not inevitably lead to subsequent pain. In fact, 4 of the 10 patients followed with the bullet still in the canal report no pain whatsoever.

Future Plans—During the coming year, subjects will continue to be enrolled in the study. Preliminary analyses of the McGill Inventory data will be conducted. The plan continues to include entering both GSW/SCI patients and matched, non-GSW/SCI patient controls through June 1989. Final data analyses will be completed at that time.

Didronel in the Prevention of Heterotopic Ossification Following Spinal Cord Injury: Determination of an Optimal Treatment Schedule

S. L. Stover, M.D.

Research and Training Center in Spinal Cord Dysfunction, University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—Heterotopic ossification (H.O.) following spinal cord injury (SCI) or other severe neurologic injuries and diseases can limit joint range of motion and exacerbate the disability, often impairing function and limiting ambulation or wheelchair independence to the extent the patient must remain bedfast. Recently, however, a drug, Didronel (etidronate disodium), has been shown effective in preventing H.O. when administered prophylactically after SCI.

This study seeks to: 1) determine the optimal time post-injury Didronel therapy should be initiated to achieve the maximal prophylactic effect; 2) determine the optimal duration of Didronel therapy for

maximal prophylactic effect; and, 3) establish dosage recommendations for Didronel that are capable of yielding maximal prophylactic effect.

Progress—The study population consists of patients admitted to the UAB Spinal Cord Injury Care System between 0 and 120 days post-injury; whose lesions are neurologically complete (or neurologically incomplete with residual function equal to a Frankel Classification of "sensory only") and who are at least 16 years of age and who are not pregnant. Patients in the series are subcategorized into Early and Late Treatment Groups and further divided into 3- and 6-month administration groups. X-ray films

of both hips are obtained 1 day prior to initiation of Didronel therapy, at the end of each treatment period, and at 1 year post-injury.

Preliminary Results—As of November 13, 1986, 169 patients/subjects had been entered into the study. Substantially more patients/subjects have been entered into the Early Treatment Groups (15-44 days post-injury) than into the Late Treatment Groups (45-120 days post-injury). The reason for this is that most SCI patients are admitted to this center well within 44 days of injury, since the UAB Spinal Cord Injury Care System emphasizes early admission. (It is imprudent to delay transfer-admissions solely for the purpose of being able to enter a prospective patient/subject into any clinical study.) In this case, it would be considered particularly imprudent since the agent, disodium etidronate, has been proved effective in the early prevention of H.O. formation. However, if patients are admitted to our center 45 or more days after injury, they are entered into one of the Late Treatment Groups routinely, if they

meet all other selection criteria.

Ten additional patients developed clinically significant H.O. requiring continued drug treatment for at least 1 year. Because of its proven efficacy, treatment cannot be withheld when patients develop clinically significant H.O. Data from these patients will be analyzed separately at the conclusion of the study.

Provisional results based on 87 patients/subjects with complete data show that, for patients who do not develop H.O. during drug treatment, treatment for 180 days appears to be no more advantageous than treatment for 90 days, regardless of when treatment begins. However, early treatment is superior to late treatment regardless of treatment duration. Data for patients developing H.O. during drug treatment are inconclusive.

Future Plans/Implications—Patients/subjects will continue to be entered into the project until the target of 100 patients/subjects with complete data is reached.

Natural History and Clinical Course of Urinary Tract Complications in Patients with Spinal Cord Dysfunction

S. L. Stover, M.D.

Research and Training Center in Spinal Cord Dysfunction, University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—Appropriate clinical management of patients with neurogenic bladders resulting from spinal cord dysfunction requires 1) knowledge of the natural history or clinical course of urinary tract complications in this group and 2) data from which to determine whether urinary complications in this group are predictable from early post-injury urinary tract status and method of early bladder drainage management.

The objectives of this study include: 1) determining the effect of method of bladder drainage management on the incidence of orchitis and/or epididymitis, penoscrotal abscess, penoscrotal fistula, ureterectasis, pyelocaliectasis, and effective renal plasma flow (ERPF); 2) determining the effect of various urinary tract infecting organisms on orchitis/epididymitis, penoscrotal abscess, penoscrotal fistula, ureterectasis, pyelo-caliectasis, and ERPF; 3)

determining the effect of vesico-ureteral reflux on upper tract changes including ureterectasis, pyelocaliectasis, calculi, and ERPF; 4) determining the effect of pyelocaliectasis on cortical thickness and development of renal calculi; and, 5) determining the effect of bladder calculi on bladder configuration changes, vesico-ureteral reflux, ureterectasis, pyelocaliectasis, cortical thickness and renal calculi and the effect of renal calculi on pyelocaliectasis and cortical thickness.

Progress—Rigorous statistical analyses are being performed on a massive urologic database derived from a large series of SCI patients having a spectrum of neurologic levels and extents of injuries, and those neurogenic bladders are/were managed in a variety of ways.

Preliminary Results—As of November 1986, the medical records of 1360 patients have been reviewed, although not every patient has been entered into the database. Objectives 4 and 5 have been completed. The findings suggest patients with treated asymptomatic bacteriuria do not have significantly fewer urologic complications, episodes of chills and fever, or therapeutic urologic surgical procedures than similar patients whose asymptomatic bacteriuria is allowed to go untreated. Moreover, 37 percent of the patients treated with antibiotics developed strains of bacteria that were antibiotic-resistant.

Patients whose urine was sterile at the first of two consecutive annual follow-up examinations had fewer urologic complications, episodes of chills and fever, and therapeutic urologic surgical procedures than patients whose urine was infected at the first examination. This finding can be explained by the fact that patients with sterile urine had some degree of bladder sensation or control. In this series, patients with untreated asymptomatic bacteriuria were more likely to have therapeutic urologic surgery than

patients with treated asymptomatic bacteriuria. Data have also been collected on a series of patients with vesico-ureteral reflux.

Future Plans—A case-controlled study is now being conducted to identify and quantify risk factors for the development of vesico-ureteral reflux. Secondly, a suitable control series will be identified who have never developed vesico-ureteral reflux. The proportion of patients who developed vesico-ureteral reflux and who were classified correctly (sensitivity) and the proportion of those patients who were vesico-ureteral reflux-free and classified correctly (specificity) will be assessed using a model to classify all patients in the study and comparing predicted with actual results.

We will also conduct a nonconcurrent prospective study to determine the effect, if any, of vesico-ureteral reflux on effective renal plasma flow, development of renal stones, pyelocaliectasis, and ureterectasis 3 years after reflux diagnosis.

Pathologic Effects of Recurrent Bacteriuria in Patients with Spinal Cord Dysfunction

K. B. Waites, M.D.

Research and Training Center in Spinal Cord Dysfunction, University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—Urinary tract infections (UTIs) are a serious source of morbidity for spinal cord injury patients. Recurrent hospitalizations and outpatient services required for treatment of acute and chronic UTIs are extremely expensive and may impede both the overall rehabilitation process and vocational pursuits. In addition, UTIs may lead to grave urologic complications and, in some cases, eventual renal failure. There is a need to prevent these infections and their sequelae so as to improve the overall rehabilitation potential and quality of life for SCI patients.

Objectives of this study include: 1) determination of the incidence of clinically significant urinary tract complications coincident with the major bacterial species; 2) determination as to whether aggressive treatment of most pathogenic organisms results in fewer long-term secondary urinary tract complications; 3) determination as to whether patients with

certain human leucocyte antigen (HLA) combinations are at unusually high or low risk for developing long-term secondary urinary tract complications; 4) determination as to whether the phagocytic activity of human leucocytes correlates with the incidence of clinically significant urinary tract infections and long-term secondary complications; and, 5) determination as to whether the degree of bacterial adherence to the urothelium correlates with the incidence of clinically significant urinary tract infections and specific HLA combinations.

Progress—Data will be analyzed to determine the effect of chronic UTI with the major bacterial species on parameters such as parenchymal thickness, reflux, effective renal plasma flow (ERPF), etc. by selecting SCI patients who have been infected for 1 year or more and comparing their data with those of uninfected patients.

SCI patients with histories of multiple urinary tract complications will be studied to determine if: a) their bacteria show a high degree of adherence to the urothelium; b) there is a particular HLA combination; or, c) they have circulating leucocytes or monocytes of unusually low phagocytic activity when compared with SCI patients who rarely or never have UTIs and with persons without SCI who have normal urinary tracts.

SCI patients with recurrent UTIs will be treated rigorously with antibiotics and followed. The effectiveness of rigorous follow-up and treatment will be assessed via comprehensive renal scintigraphy procedures (CRSPs), excretory urograms (EXUs), and by carefully documenting reinfection rates.

Preliminary Results—Based on 1,461 routine annual SCI follow-up examinations, the incidence of chills and fever, specific urologic surgical procedures, and the mean effective renal plasma flows (by specific genera of bacteria) has been determined. These data indicate that patients whose urinary tracts were infected with *Serratia*, *Pseudomonas*, *Providencia*, and *Acinetobacter* were more likely to have urologic complications and episodes of chills and fever than

patients whose urinary tracts were infected with *Staphylococcus*, *Enterococcus*, and *Enterobacter*.

A series of experiments has been designed comparing bacterial adherence in the urinary tract, effectiveness of urine and serum opsonization, phagocytosis, and intracellular bacterial killing by neutrophils among three groups of patients: 1) those who have urologic complications; 2) those who do not have urologic complications; and, 3) non-SCI controls.

Future Plans—In the upcoming grant period, differences in phagocytic activity of neutrophils, opsonization capacity of serum and urine, intracellular bactericidal activity, and bacterial adherence in the urinary tract that exist among SCI patients with clinically significant urinary tract infections and urologic complications, SCI patients with either sterile urine or uncomplicated bacteriuria, and normal controls without SCI or history of urinary tract disease, will be determined. HLA typing will be initiated for the purpose of determining if specific HLA types correlate with either the incidence of urologic complications or the degree of bacterial adherence.

Drug Effects on Bladder Smooth Muscle Contractility

W. T. Woods, Ph.D., and J. K. Bubien, Ph.D.

Research and Training Center in Spinal Cord Dysfunction, University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—Debilitating spasticity is an extremely serious secondary complication in patients with spinal cord dysfunction. Skeletal muscle relaxants are commonly prescribed to counteract spasticity, but experience has shown widely varying degrees of success. The bulk of previous research with these drugs has addressed their effects on skeletal and to a lesser extent, cardiac muscle. Their effects on smooth muscle have been considered only rarely. This study examines the role of skeletal muscle relaxants on arterial and intestinal smooth muscle contractions in rats, and on bladder smooth muscle in humans.

Objectives of this project include: 1) determination of the effect of baclofen (lioresal) and diazepam (Valium) on *in vitro* human bladder smooth muscle

contractions induced by electrical pulses or acetylcholine; 2) determination of the effect of baclofen and diazepam on *in vitro* rat arterial and intestinal smooth muscle contractions induced by electrical pulses or acetylcholine; 3) determination as to whether diazepam or baclofen alter the responses of rat bladder, arterial, and intestinal smooth muscle induced to contract by bethanechol chloride; and, 4) determination as to whether diazepam or baclofen alter the length-tension relationship of rat bladder, arterial, and intestinal smooth muscle.

Progress—Smooth muscle tissue specimens will be obtained surgically in accordance with institutionally approved guidelines governing the involvement of human subjects in research projects. *In vitro* tension

measurements resulting from artificially induced contractions under control and experimental (with drug) conditions will be obtained. Inter-species drug

effects on different tissue specimens will be determined and compared. (The project began June 1, 1987.)

Surface Sacral Stimulation for Bladder Management of Patients with Spinal Cord Injury

John S. Wheeler, M.D.; James S. Walter, Ph.D.; Charles J. Robinson, D.Sc; D. Gerfen

Hines VA Hospital, Rehabilitation Research and Development Center, Hines, IL, and Loyola Medical Center, Department of Urology and Physiology, Maywood, IL

Sponsor: Neuroscience and Aging Institute, Loyola University, Stritch School of Medicine

Purpose—Control of bladder functions of continence and voiding are lost in many spinal cord injured (SCI) patients. Because of this many problems are faced including urinary incontinence, urinary infection and high bladder pressures which can result in urological pathology. There is a need for control of bladder contraction for voiding and control of bladder inhibition to prevent incontinence and high bladder pressures.

Sacral stimulation has been effective in clinical trials using cuff electrodes on sacral nerve roots within the sacral canals (Brindley et al., *J Neurol Neurosurg and Psychiatry* 49:1104, 1986). However, invasive surgical implantation procedures, including laminectomy and entry inside the dura for implanting nerve cuff electrodes, have been required. Less invasive electrode implantation methods are needed. In clinical trials, surface electrodes over sacral foramina are being evaluated. Optimum electrode arrangements and stimulating parameters are being determined. Criteria will be established for: 1) bladder contraction: effective voiding at low bladder pressures, less than 20 stimulations to empty the bladder with less than 100 cc residual urine; and, 2) inhibiting bladder contractions: reduce or eliminate bladder contractions induced by cystometry.

Less invasive methods of sacral stimulation can be used for bladder management. Sacral stimulation

with surface electrodes can effectively stimulate bladder motor fibers, induce bladder contraction and voiding, or inhibit unwanted bladder contractions.

Progress—Previously, we managed the bladders of one chronic spinal male and female dog for over 2 years using similar procedures to those described here (Tang and Walter, *Neurourol and Urodyn* 3:43-50, 1984). We are also completing studies comparing sacral implanted needle electrodes to sacral surface electrodes in chronic spinal male dogs. The current studies concern using surface sacral electrodes in the SCI patient.

Three evaluations are being conducted to meet our goal of bladder management with sacral stimulation in the SCI patient. 1) Determine optimum electrode arrangements: surface electrodes over the S2 sacral foramina appear to be optimal. 2) Determine optimum stimulating parameters: preliminary results in one patient indicate that five seconds bursts of 20 pps stimulation at currents of 35 to 40 mA are effective for inducing bladder contraction. However, in a second patient, our highest stimulating current of 60 mA was ineffective. 3) Determine urodynamic responses: effective voiding remains to be shown.

Neuroaugmentative Procedures for Modification of Abnormal Motor Control in Patients with Spinal Cord Injury

M.R. Dimitrijevic, M.D.; A.M. Sherwood, P.E., Ph.D.; R.J. Campos, M.D.; P.C. Sharkey, M.D.
Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *Rehabilitation Research and Training Center on Spinal Cord Dysfunction; National Institute on Disability and Rehabilitation Research*

Purpose—Sixty patients with muscle hypertonia after spinal cord injury have undergone spinal cord stimulation (SCS). These patients had spinal cord injuries (SCI) ranging from C2 to T12. Electrodes were placed above, below, or above and below the lesion in the posterior epidural space for a period of at least three days during which time stimulation pulses, typically of 3 to 5 mA amplitude and of 0.2 msec duration at 30 Hz were applied. The effects of SCS were monitored by recording motor unit activity with surface electrodes over leg muscles during an examination of segmental and suprasegmental spinal cord activity, in addition to patient reports and neurological evaluations.

Progress—The results of SCS can be divided into four distinct categories. In Group I, consisting of 17 patients, or 28 percent of the entire group, the effect was characterized by marked suppression of muscle hypertonia and so-called spontaneous spasms. In Group II, the effect of SCS on muscle hypertonia was moderate, as evidenced by the suppression of the tonic but not phasic features of spasticity. This was observed in 20 patients, or 33 percent of the total. In Group III, neurological and neurophysiol-

ogical evaluations revealed only a marginal effect. The condition of this group of nine patients (15 percent) did not improve significantly. In group IV, consisting of 14 patients (23 percent), there was no effect.

Preliminary Results—SCS was markedly or moderately effective in reducing spasticity in 63 percent of the patients. We found that control of spasticity by SCS was not correlated with the severity of spasticity, the type of spasticity (flexor or extensor), or the ability to ambulate. However, stimulation in incomplete cervical lesion patients was 90 percent effective, compared to 14 percent effective in complete cervical lesions, and stimulation below the lesion was more effective than above. We concluded that SCS is effective when electrodes are properly positioned below the lesion over the posterior aspect of the spinal cord in patients with some residual spinal cord function. We hypothesize that SCS controls spasticity by modification of activity of the spinal-brainstem-spinal loop and by suppression of segmental excitation through antidromic activation of propriospinal pathways.

Effects of Spinal Cord Injury on Drug Metabolism

Lauro Halstead, M.D. and Stuart Feldman, M.D.

Baylor College of Medicine; The Institute for Rehabilitation and Research; Department of Pharmaceutics, University of Houston, Houston, TX 77030

Sponsor: *Rehabilitation Research and Training Center on Spinal Cord Dysfunction; National Institute on Disability and Rehabilitation Research; Paralyzed Veterans of America*

Purpose—The pharmacokinetics of medications administered to spinal cord injured (SCI) patients have not been widely investigated. There are numerous reports regarding alterations of normal physiological, neurological, and biochemical functions in the SCI population which raise the possibility that one or more aspects of drug distribution, metabolism, and excretion may be altered in this group. The

overall objective of this research is to investigate, in a systematic fashion, a number of representative drugs commonly used at various times throughout the life of SCI patients.

Progress—Eighteen subjects with SCI who were to receive tobramycin, either prophylactically prior to a urological procedure, or to treat infection, were

given an explanation of the research project and gave written informed consent. All subjects had normal renal function as evidenced by creatinine clearance measurements. Eighty milligrams of tobramycin were infused intravenously by a pump over a 60-minute period. Serum samples were collected before the infusion and at 30, 60, 75, 90, 120, 150, 180, 240, 360, and 480 minutes after the start of the infusion. Serum samples were assayed for tobramycin by the EMIT method of analysis. Data were analyzed by the model-independent pharmacokinetic methods. The mean age of our subjects was 31 years (range 18 to 54); the mean weight was 66 kg (range 45.5 to 82.7); and level of injury was from T4 to C3.

Results—Following the infusion peak, tobramycin in serum concentration averaged 3.4 ± 0.8 g/ml. At the end of the 8-hour dosing interval, trough levels averaged 0.3 ± 0.2 g/ml. In the 18 subjects studied, the mean half-life of tobramycin was 113 minutes. The serum clearance (Cl) averaged 147 ± 40 ml/min or 23.5 ± 7.3 liters or 0.36 ± 0.10 .

The data in the limited population studied strongly suggests that the disposition of tobramycin in per-

sons with SCI may be quite different than in people with intact spinal cords. Both the volume distribution (V_{ss}) and clearance appear to be higher in SCI. Data published for tobramycin in the intact spinal cord subject indicates average clearance values of approximately 1.87 ml/min/kg and a mean volume of distribution of 0.26 l/kg. The physiological basis for the differences are not known, but these data suggest that dosages of tobramycin in patients with SCI requiring aminoglycoside therapy may have to be increased to provide serum concentrations to adequately cover susceptible organisms. Trough serum tobramycin concentrations were < 0.30 µg/ml. If one assumes that trough tobramycin serum levels should be approximately 1 µg/ml, we found that in our study population the aminoglycoside concentration falls below this level at four hours post-dosing. Thus, a change in tobramycin dosage regimen in SCI patients would be appropriate.

Future Plans/Implications—Further studies will examine the absorption of tobramycin following intramuscular administration to spinal cord injured subjects to determine if spinal cord injury affects the absorption of drugs.

Collagen Dysfunction in Quadriplegia

Gladys Rodriguez, M.S. and Jacqueline Claus-Walker, Ph.D.

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *Rehabilitation Research and Training Center on Spinal Cord Dysfunction; National Institute on Disability and Rehabilitation Research; Spinal Cord Research Foundation of the Paralyzed Veterans of America*

Purpose—This study seeks to elucidate the ways in which collagen metabolism is altered in spinal cord injury (SCI), and determine the causes and consequences of such alteration.

Project I: A method has been developed to measure hydroxylysine glycosides in an automated amino acid analyzer to establish the fact that increased concentration of a specific glycoside is an indication of the tissue origin of the collagen being degraded. It is hoped that physicians will be able to use this information to decide what preventive measures are of greatest importance for the individual patient and thus reduce the number of complications following SCI.

Project II: Density of adrenergic receptors in the insensitive skin of SCI patients is being measured by radioligand binding assays. The objective is to

show that altered sympathetic responses lead to altered nutritional status of the skin, thus increasing its susceptibility to pressure damage.

Project III: The activity of the enzyme lysyl hydroxylase and the concentration of some amino acids characteristic of collagen are being measured in skin biopsies from above and below the injury in SCI patients. The objective is to show that SCI leads to abnormal enzyme activity which in turn leads to defective collagen biosynthesis and decreased tensile strength of the skin. If the specific defects in the collagen metabolism of SCI can be identified, they may be amenable to pharmacological intervention.

Progress—Project I: Eighty-six patients have been followed. Results show that approximately one month

prior to any physical incidence of skin irritations, the urinary concentration of the diglycoside increases and remains elevated until the condition is corrected. Increased concentrations of monoglycoside are associated with the incidence of urolithiasis, heterotopic ossification, and osteoporosis, but the temporal relationship is not as clearly defined.

Project II: Data has been published in the *Archives of Physical Medicine and Rehabilitation*, 67:177-180, 1986.

Project III: Biopsies have been obtained from healthy, nonparalyzed volunteers. The number of patients is small, but data so far indicates that lysyl hydroxylase activity is highest in healthy controls, next highest in the skin above the level of injury in SCI patients, and lowest in skin below the level of injury of SCI patients. Also, amino acid content of skin below the level of injury is much lower than in the skin above the level of injury in the same patients.

C. Spinal Cord Regeneration

Electric Field Distribution in the Injured Spinal Cord

Talat Khan, Ph.D.; Joel B. Myklebust, Ph.D.; Thomas Swiontek, Ph.D.; Dennis Maiman, M.D., Ph.D.; Robert D. Wurster, Ph.D.

Veterans Administration Medical Center, Hines, IL 60141 and Zablocki Veterans Administration Medical Center, Milwaukee, WI 53295

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Injury to the spinal cord causes paraplegia or tetraplegia. Currently, there is little hope for functional recovery after spinal cord trauma; victims are often confined to bed or wheelchair. Although rehabilitation and orthotic devices aid these patients in enriching the quality of their lives, the ideal solution to the problem is a regimen which would enhance the regrowth and reconnection of the traumatized nerve fibers, so that functional neural connections can be reestablished.

Externally applied electric field has been shown to produce beneficial effects on the regrowth of injured spinal cord axons and other peripheral and central nerve fibers. In any attempt to stimulate regeneration in the mammalian spinal cord, it is quite important to provide some assistance to guide the direction of nerve growth if the axons are to make specific functional connections with their normal target tissues. In tissue culture, externally applied electric fields not only stimulate the nerve fiber growth but also influence the direction of that growth. Fibers grow extensively towards the cathode. Although fiber growth *in vitro* can be guided by externally applied fields, the application of these methods *in vivo* is limited because of the lack of information regarding current pathway and electric field distribution. In contrast to the controlled en-

vironment of tissue culture media, the spine and spinal cord is a highly inhomogenous and anisotropic structure.

Properly configured, applied electric fields should aid in guiding regenerating spinal cord axons. If the effect of electric currents upon regeneration is to be properly evaluated, the distribution of electric current and potential in the tissue must be determined for electrode configurations and electrical parameters which are suggested to produce stimulating effects. Furthermore, because it has been reported that currents are produced endogenously in the vicinity of an injury to the spinal cord and that this "injury current" is related to the potential healing process, it is important to measure the effect of the applied electric current on these endogenous electric fields. Following the determination of current and potential distribution in the spinal cord, those configurations which produce the best results will be used in cats after contusion or transection injury.

Progress—Previously we have used electrical currents of small magnitude on the injured spinal cord of rats. Initial evidence of clinical assessment of neurological function indicated a favorable response to the extrinsically applied electric fields after spinal

cord injury. However, accurate dosimetry which is essential to the optimum response to treatment should be determined.

Four evaluations will be made during the course of this project: 1) measurement of the distribution of electric fields in the spinal cord of the cat before and after spinal cord injury by contusion and transection; 2) measurement of the electric fields in the spinal cord resulting from applied currents from implanted electrodes; 3) correlation of the degree of axonal regrowth due to neural stimulation with electric fields distribution; and 4) implementing a standard measure of comparison, that is, current density measurement, to evaluate neural stimulation techniques with different electrode configurations

and stimulation parameters.

The initial studies (first 3-4 months) will focus upon the determination of appropriate electrical parameters for the *in vivo* studies of axonal regrowth. Following this, the electrical and neurophysiological experiments will be conducted in parallel. At the end of the first year, the results of the histologic studies will be reviewed together with the electrical measurements to determine whether particular combinations of electrical parameters is more efficacious than others. If this is the case, the experimental protocols will be modified to concentrate upon those parameters. Otherwise, the studies will be continued to evaluate a wide spectrum of electrical parameters.

Recovery Following Incomplete Spinal Cord Injury: An Animal Model

James W. Little, M.D., Ph.D., and Roger M. Harris, Ph.D.
University of Washington, Seattle, WA 98105

Sponsor: VA Rehabilitation Research and Development Service; University of Washington

Purpose—Recovery of voluntary movement is characteristic of incomplete spinal cord injury (SCI). Such recovery is observed even though a majority of descending axons are sectioned and degenerate; they do not regenerate. The spared descending axons apparently take over some function for those lost. This research undertakes to develop a practical animal model for investigating the mechanisms that mediate recovery and any interventions which might enhance recovery.

Progress—Adult rats undergo mid-thoracic subtotal spinal cord section, sparing either one ventral or one lateral funiculus. Hindleg locomotor and postural recovery and spinal reflex changes are described over 4 to 6 weeks after the cord lesion. Some locomotor recovery is supported by fewer

than 25 percent of descending fibers, and neither the dorsal half of the lateral funiculus nor the medial half of the ventral funiculus is necessary to mediate that recovery. Anterograde labelling of lumbar commissural axons and terminals, crossing from the side of the cord with spared descending fibers to the side without spared fibers, has failed to demonstrate any morphologic increase in this projection to explain the motor recovery.

Future Plans/Implications—Future studies will look for morphologic changes, such as collateral sprouting and new synaptogenesis by other spared commissural projections, to explain the motor recovery. This animal model of incomplete spinal cord injury will be used in trials of various therapeutic interventions which may enhance recovery.

Lower Extremity Spasticity Following Spinal Cord Injury

James W. Little, M.D., Ph.D.
Veterans Administration Medical Center, Seattle, WA 98108

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Spasticity represents hyperactive spinal reflexes. Such exaggerated reflexes commonly de-

velop in spinal segments caudal to a spinal cord injury (SCI). Such hyperreflexia can further com-

promise patient function. This study examines the lower extremity manifestations of SCI spasticity and will describe the time-course for the appearance of the hyperreflexia over the first year post-SCI.

Progress—To date, serial spinal reflex studies have been initiated in 11 acute and 11 chronic SCI subjects with complete injuries. Tibial and femoral H reflex excitabilities, measured as H/M amplitude ratios, tend to increase during the first three months post-injury. Tendon reflex excitability also increases over time, in many but not all subjects, and is most excitable in chronic SCI subjects. Flexor withdrawal reflexes, recorded in the biceps femoris and tibialis anterior muscles, tend to be larger amplitude and lower threshold in chronic as compared to acute SCI subjects. Reflex excitabilities are measured as fractions of the compound muscle action potential amplitude, since this amplitude falls markedly with

disuse atrophy in the lower extremity muscles.

Results—A survey of lower extremity spasticity manifestations in SCI subjects has revealed that hyperactive tendon reflexes, clonus and extensor spasms commonly appear together. Spontaneous flexor spasms and triple flexion response with plantar stimulation of the foot are regularly seen together. Those with incomplete spinal cord injuries note more functional limitations due to their spasticity than do those with complete cord injuries. Quadriplegics and those with complete cord injuries report more functional use from their spasticity than do paraplegics and incompletes.

Future Plans/Implications—Future studies will examine reflex changes in incomplete SCI subjects and the effect of motor recovery on those changes.

The Neurite-Promoting Activity of the Basement Membrane Protein Laminin

Eva Engvall, Ph.D. and Matia Bar-Ner, Ph.D.

LaJolla Cancer Research Foundation, Cancer Research Center, LaJolla, CA 92037

Sponsor: National Cancer Institute

Progress/Methodology—Laminin promotes neurite outgrowth from cultured neuronal cells and promotes the adhesion and motility of glioblastoma cells *in vitro*. Laminin-containing acellular fetal membranes also show activity in nerve regeneration *in vivo*.

We have located the neurite-promoting site in human laminin to the end of the long arm using monoclonal antibodies to laminin and proteolytic fragments. We have evidence suggesting that glioblastoma cells interact with the same site and that the receptors on neuronal cells and glioblastoma cells are related. We propose to identify and characterize the neurite-promoting/cell adhesion site of laminin by isolating smaller active proteolytic fragments of laminin and analyzing these fragments by rotary shadowing-electron microscopy, electrophoresis, NH₂-terminal sequencing of peptide subunits, and antibody reactivity. Complete structural infor-

mation on the neurite-promoting site will be obtained from cloning and sequencing of cDNA coding for sequences around the site.

We will reconstruct the neurite-promoting site using peptide synthesis and/or synthesis in bacteria and test the constructs for *in vitro* and *in vivo* activity. The human cell surface receptor interacting with the neurite-promoting site in laminin will be identified, characterized, and isolated from glioblastoma cells using monoclonal antibodies and affinity-chromatography on natural or synthetic neurite-promoting/cell binding sites of laminin. The relationship of the glioblastoma cell laminin receptor to other laminin receptors on other cell types and to other extracellular matrix receptors will be established. The activity of the laminin receptor will be evaluated in various *in vitro* assays using specific peptides with neurite-promoting activity and using antibodies specific for this receptor.

Central Nervous System Regeneration in Adult Mammals: A Study of Inappropriate Terminal Axonal Contacts

Albert J. Aguayo and Garth M. Bray

Neurosciences Unit, The Montreal General Hospital Research Institute and McGill University, Montreal, Quebec H3G 1A4, Canada

Sponsor: Paralyzed Veterans of America, Spinal Cord Research Foundation (NBR-657)

Purpose—Experiments in this laboratory which utilized new techniques for the examination of neural tissues, established that several different classes of nerve cells in the brain and spinal cord of adult rats have the capacity to regrow lengthy axons if their environment is appropriately manipulated. Furthermore, we subsequently demonstrated that some of these regrown axons can form differentiated contacts (synapses) when they are guided to target regions of the brain. This anatomical reconnection of widely separated central nervous system (CNS) neurons was made possible by the interposition of long segments of peripheral nerve between the damaged fibers and their targets. In addition to determining if such experimental re-connectivity is functional or appropriate, it is also important to assess the extent to which unusual and inappropriate synapses can form between cells that do not normally connect with each other. If such aberrant contacts are a common feature of this type of regeneration, the experimental development of functional re-connectivity may well require the applica-

tion of strategies to prevent or eliminate such undesirable connections.

As an initial step in this direction of investigation, we will use peripheral nerve grafts to produce aberrant connections between selected groups of CNS neurons and also with skeletal muscle. Such studies are essential to the understanding of the freedoms and constraints that the injured adult CNS may impose on the connectivity of different groups of nerve cells when multi-functional fiber systems are stimulated to regrow.

Implications—The recovery of a predictably beneficial function after CNS injury will depend largely on the possibility that cellular mechanisms can be manipulated so that the formation of appropriate synapses can be stimulated and enforced while avoiding and eliminating incorrect contacts. With the development of the proposed system of clearly inappropriate synapses, it may then be feasible to use experimental manipulations to minimize the formation of such undesirable connections.

Immunocytochemical Analysis of Localized Extracellular Proteolysis During Neuronal Development

M.J. Anderson, Ph.D.

The University of Calgary, Department of Pharmacology and Therapeutics, Calgary, Alberta T2N 4N1, Canada

Sponsor: Paralyzed Veterans of America, Spinal Cord Research Foundation (NBR-665)

Purpose—Spinal cord injuries are more devastating than others because the central nervous system (CNS), unlike most parts of the body, fails to heal itself. This does not happen because there are no physiological repair processes in the nervous system; rather it is a result of a breakdown of these healing mechanisms in the CNS. In fact, the inability to repair injuries to the CNS is a hereditary problem we share with all mammals, but not with other "lower" animals. The CNS may ultimately be helped to repair itself, therefore, providing we can deter-

mine how the healing process has gone awry. However, this leads us to a more immediate problem: we still do not understand how nerve regeneration is controlled, and thus cannot determine what is wrong when it fails.

Our approach involves removing nerve cells from an embryo to place them in miniature aquaria, where we can observe their growth through a microscope. For these experiments we use embryonic cells from frogs and salamanders, because they develop much faster than those from humans. However, like hu-

man nerve cells, they also grow to their appropriate targets and interact with them to form synapses, the specialized cell contacts that allow electrical signals to flow within the nervous system. This kind of experimental system allows us to study the unknown signalling mechanisms which control nerve growth and development, and are likely to be similarly involved in human CNS regeneration.

Progress—In our current research we are studying the interesting possibility that growing nerve cells may chemically digest minute amounts of their surrounding environment, and then use the products of this digestion both to determine where they are, and to exchange signals with the cells they touch. This local digestion, occurring where growing nerves contact other structures or cells, may also release hormone-like substances that affect nearby cells,

causing them to regenerate the structures that were lost following injury. This kind of process could allow injured neurons to find their way back to their target cells, and then to rebuild their lost synapses, reestablishing the situation that existed before they were damaged.

Implications—If this hypothesis turns out to be correct, we may eventually be able to identify inappropriate chemical agents in the injured CNS that misdirect regenerating human nerves, and find ways to remove them. Alternatively, we may find that important chemical road-signs are missing in the injured human CNS, and be able to replace them. In either situation, it could become possible to assist the body's repair process, leading eventually to functional neuronal regeneration, the only really adequate treatment for spinal cord injury.

Regeneration of Spinal Projection Neurons in a Peripheral Nerve Environment

Mary Blair Clark, Ph.D.

University of Maryland School of Medicine, Department of Anatomy, Baltimore, MD 21201

Sponsor: *Paralyzed Veterans of America, Spinal Cord Research Foundation (Proposal 645)*

Purpose—This project addresses the problem of regeneration of the central nervous system's corticospinal neurons. Corticospinal neurons extend long axons from the cerebral cortex to the spinal cord. These neurons carry information from the brain to motor neurons in the spinal cord and thereby direct much of the motor activity of the body. It is not known if corticospinal neurons which extend axons from the cerebral cortex to the spinal cord are able to regenerate under any circumstances. This is critical information in attempting to experimentally influence repair after spinal cord injury. We will determine if components of the peripheral nerve which are known to promote survival and growth of some types of central neurons also support corticospinal neurons. We will use brain cell cultures to evaluate the trophic and neurite promoting contributions by cellular and extracellular matrix components of peripheral nerve. The specific objectives

are: 1) to obtain cultures of corticospinal neurons identified by retrograde labeling *in vivo*; 2) to compare the survival and neurite outgrowth requirements of corticospinal neurons to those for cerebral cortical interneurons; and 3) to determine the relative contributions by specific cellular components of peripheral nerve to such support.

Future Plans/Implications—After we have identified the cellular source(s) of trophic and neurite promoting factors for corticospinal neurons, the isolation and characterization of the factor(s) will be pursued in collaboration with Dr. T.L. Wallace, Baylor Center for Biotechnology, Baylor School of Medicine and transplantation studies will be done in collaboration with Dr. B. Bregman to evaluate the effectiveness of the cellular sources of the factor in promoting regeneration in spinal lesioned animals.

Rapid Neuronal and Glial Changes in the Spinal Cord Following Injury

Harry G. Goshgarian, Ph.D.

Wayne State University, School of Medicine, Detroit, MI 48201

Sponsor: *Paralyzed Veterans of America, Spinal Cord Research Foundation (Proposal #NFR-625)*

Purpose—The ultimate goal of all spinal cord injury research is to achieve functional restitution. Spinal cord regeneration research is directed toward establishing functional restitution by the growth of new axon pathways through the damaged regions of the spinal cord. Another approach to functional recovery after spinal cord injury would be to activate already existing, functionally latent axon pathways which survive spinal cord injury and are found in the non-damaged regions of the spinal cord. Recently, several examples of functionally latent pathways have been demonstrated, not only in the spinal cord, but in many other regions of the central nervous system as well. The pathways are latent because the synapses which connect them to neurons in the CNS initially are functionally ineffective in firing the postsynaptic cell. Within hours after injury, however, the functionally ineffective synapses are converted to ones which become capable of activating the postsynaptic target neuron. In many instances, the functional capabilities of the animal are markedly improved after synaptic conversion. Although the functional unmasking of ineffective synapses has been demonstrated physiologically in many regions of the CNS, the morphological basis for the synaptic conversion has not been discovered.

For years, the P.I. has associated functionally ineffective synapses with the expression of a respiratory reflex in spinal cord injured rats. In this model, the conversion of the ineffective synapses to effective ones results in the functional recovery of a portion of the animal's diaphragm which had been paralyzed by spinal cord injury. Through an extensive electron microscopic analysis of the phrenic nucleus (the location of neurons in the spinal cord which are responsible for diaphragm contraction) in normal and spinal cord injured rats, the P.I. has

discovered specific morphological alterations of the normal phrenic nucleus ultrastructure occurring within hours after injury which he hypothesizes are related to the conversion of functionally ineffective synapses. Such alterations have never before been shown to occur so rapidly after spinal cord injury. Current laboratory experiments are designed to substantiate the relationship of morphological findings to the physiological conversion of functionally ineffective synapses. This is being accomplished by using computer-aided morphometric analysis techniques to quantitate the observed morphological alterations and then comparing these data with earlier physiological results.

The goals of the research proposed are: 1) to begin to more clearly focus on the specific physiological conditions which induce the observed morphological alterations in the phrenic nucleus within hours after spinal cord injury in rats; and, 2) to determine if these morphological changes may not also be detected in other motor nuclei of the injured spinal cord. Horseradish peroxidase (HRP) will be used to label phrenic motor neurons or neurons innervating the hindlimb musculature at electron microscopic levels. A digitizing tablet will be used to feed several specific morphological characteristics of these labeled cells into a computer. The computer will demonstrate any significant differences in morphology among these cells after manipulation of the animals in the experimental groups.

Implications—When this work is complete it will provide important new information pertaining to the rapid changes that can occur in the spinal cord after injury and how these changes may be related to the functional recovery of paralyzed muscle.

The Effect of a GABA Agonist and a GABA Antagonist on Motor Recovery Following Subtotal Spinal Cord Lesions

Roger M. Harris, Ph.D. and James W. Little, M.D., Ph.D.

University of Washington, Department of Biological Structure, Seattle, WA 98195

Sponsor: *Paralyzed Veterans of America, Spinal Cord Research Foundation (Proposal 635)*

Purpose—Traumatic spinal cord injury in humans is often followed by some recovery of voluntary movement below the injury. In some individuals, the recovery allows return of motor function; in others, the recovery is minimal and movements are non-functional. Recent observations suggest that the inhibitory neurotransmitter gamma-aminobutyric acid (GABA) may either enhance or limit motor recovery within the spinal cord. This study will examine the effect of a GABA agonist and a GABA antagonist on motor recovery in an animal model of spinal cord injury.

Adult rats will undergo midthoracic three-quarter lesions of the spinal cord, sparing the left ventral funiculus. These rats will be assigned to one of three groups, each of which will receive a daily intraperitoneal injection for one month. Group 1 will receive Baclofen, a GABA agonist; Group 2 will receive Bicuculline, a GABA antagonist; and Group 3 will receive saline, as a control. The temporal course and final level of motor recovery will be observed over a 3-month period and will be used to detect

any improvements in motor recovery as a result of the drug injections.

After 3 months, these rats will be injected with horseradish peroxidase (HRP) within the left lumbar gray matter or thoracic ventral funiculus, in order to detect anatomical evidence for axonal sprouting as a mechanism for motor recovery. After 24 hours, the injected animals will be sacrificed and spinal cord sections processed histologically to visualize the anterograde transport of HRP into lumbar commissural axons and axon terminals. Comparison of this anterograde labeling with labeling from similar injections in nonlesioned rats will show whether axonal sprouting has occurred in the lesioned animals.

Implications—This study may lead to new treatment strategies which can promote recovery of motor function after spinal cord injury, as well as investigating the underlying mechanisms responsible for motor recovery.

Spinal Cord Synaptogenesis in Response to Deafferentation and Alterations in Nerve Growth Factor

Claire Elizabeth Hulsebosch, Ph.D.

University of Texas Medical Branch, Galveston, TX 77550

Sponsor: *Paralyzed Veterans of America, Spinal Cord Research Foundation*

Purpose—Several types of spinal neural elements are damaged after spinal cord injury and this often results in a devastating loss of function. Thus, for appropriate return of function, several populations of nerve cells and fibers require reorganization. One important task toward gaining insight into procedures that results in spinal cord restitution is to understand precisely the capacity of axons to sprout in the spinal cord after denervation. Specific denervation procedures will be used, followed by quantitative analysis at the light and ultrastructural level to assess the sprouting response of synapses of primary afferents in the dorsal horn.

Another important task toward spinal cord restitution is to manipulate the sprouting response by factors which may be beneficial clinically. Nerve Growth Factor (NGF) is known to affect the growth and development of sensory and sympathetic neurons. Previous work in this laboratory demonstrates that sprouting of primary sensory neurons can be dramatically increased by manipulations of the levels of endogenous NGF. However, it is not known if these new sprouts make synaptic contacts in the neuropile of the dorsal horn. Specific projects will give insight into the amount of synaptic sprouting in two experimental situations: 1) surgically induced

denervation; and, 2) manipulation of endogenous levels of NGF. The procedures will be to quantitate the distribution of a stain specific for presynaptic terminals of unmyelinated primary afferent fibers (fluoride resistant acid phosphatase or FRAP) at the light and ultrastructural level.

Future Plans/Implications—These projects will pro-

vide a base for future studies which will combine stereologic techniques coupled with immunohistochemistry to assess not only the degree of presynaptic terminal distribution but the class of preterminal constituents (i.e., substance P, somatostatin, methionine-enkephalin, etc.) which responds to the paradigms.

A Study to Determine if Localized Extracellular Proteolysis is a Requirement for Successful Regeneration of Nervous Tissue

Nurit Kalderon

The Rockefeller University, New York, NY 10021

Sponsor: *Paralyzed Veterans of America, Spinal Cord Research Foundation*

Purpose—The working hypothesis of this project is that proteolytic activity is an essential process in achieving successful repair in a damaged nervous system. However, proteolytic activity, rather than general or random, must be a localized one. Namely, general injection of these enzymes can lead to an uncontrolled tissue destruction, whereas localized proteolysis, e.g., the plasmin-generating system, which is expressed by certain cells in a highly controlled manner, will remove only the unwanted tissue in the path of the growing regenerating axons.

Progress—The experimental design of this proposal was set to assess the validity of this hypothesis. Assuming that localized proteolysis is essential for regeneration, any treatment which will inhibit this activity, i.e., drugs or cells which produce protease inhibitors, should intervene and prevent the regenerating process. On the other hand, any other cell type which is known to produce this specific proteolytic activity, i.e., the immature astrocyte, Schwann cell, or tumor cell lines, should support neuronal regeneration when implanted in the injured tissue. In the same line of logic, removal of cellular components which presumably produce protease inhibitors, e.g., the glial scar, should facilitate the repair process. Two model systems of regenerating nervous tissues are being utilized: peripheral, i.e.,

sciatic nerve, and central, i.e., olfactory bulb with regeneration induced by various grafts into it.

Preliminary Results—Studies performed in the first year of the project followed the experimental strategy mentioned above, and two objectives were accomplished: it was shown that astrocytes which are deficient in extracellular proteolytic activity impair the regeneration process, and some experimental conditions were identified for the prevention of glial scar formation at the site of injury. This selective cell elimination was achieved by the cancer therapeutic procedure of irradiation of the injured tissue.

Future Plans/Implications—Future studies are focused on identifying the conditions under which, on the one hand, glial scar formation will be prevented and, on the other hand, the damaged tissue will regain functional activity. If the goal of this project is obtained and the working hypothesis is verified, novel avenues will be opened for research into possible therapeutic procedures to induce repair/recovery in any injured nervous system. One of these could be the development of a device which will apply these proteolytic enzymes of the plasmin-generating system in a localized manner at the locus of injury.

Modulation of Protein Phosphorylation in a Regenerating Central Nervous System (CNS) Tract

Denis C. Larrivee, Ph.D. and Bernice Grafstein, Ph.D.

Department of Physiology, Cornell University Medical College, New York, NY 10021

Sponsor: *Paralyzed Veterans of America, Spinal Cord Research Foundation*

Purpose—The axon is the branch of a nerve cell that enables it to communicate with other nerve cells. When the axon is injured, the part that is separated from the cell body degenerates and the nerve cell can no longer communicate with its neighbors. To reestablish communication, the axon must be reconstituted and the former target cells recontacted. In the mammalian central nervous system, injury to the axon fails to elicit a regenerative response, whereas axons in the central nervous system of lower vertebrates are successfully reconstituted and their target cells appropriately selected. Many of the cellular changes associated with reconstitution of the axon and its terminal connections have been well characterized in a number of such regenerating systems, but the manner in which the cell regulates the production of materials required for reconstitution of the axons and their terminal connections is poorly understood at the molecular level. It would be of great interest, therefore, to determine the salient features pertaining to molecular regulation of the regenerative process in these cells, so as to have a firm basis on which therapeutic measures could be explored in non-regenerating mammalian neurons.

One of the primary mechanisms for regulation of metabolic changes in neurons is protein phosphorylation (Browning et al., 1985; Nestler et al., 1984). When a protein kinase transfers the terminal phosphate from ATP to a substrate protein, the change in conformation induced in the protein results in a change in its function. This mechanism is important, for example, in the operation of known second messengers such as cAMP or calcium through the

activation of specific protein kinases.

Progress—In the previous grant period, we identified a number of phosphoproteins in the optic nerve of the goldfish, which undergoes particularly vigorous regeneration after injury. Many of these proteins were shown to be axonal proteins and to change their level of phosphorylation during regeneration. The changes in phosphorylation were largely independent of protein synthesis and were associated with particular stages of regeneration. These phosphoproteins may therefore be important targets of post-synthetic regulatory mechanisms that become operative during particular phases of optic nerve regeneration. In the proposed experiments we intend to continue our examination of these proteins to define more clearly their role in regeneration. Our particular purpose will be to determine the molecular mechanisms which contribute to changes in the phosphorylation of these proteins since this will enable us to understand how the cell can regulate their phosphorylation and presumably their function.

Future Plans/Implications—In the long term we hope to be able to find ways in which phosphorylation of these proteins can be modulated selectively. By doing so, it may become possible to promote one or another stage in the regenerative process. Should similar mechanisms exist in mammalian neurons, we hope to be able to manipulate such mechanisms in these cells and so promote regeneration in the injured mammalian central nervous system.

Dorsal Root Axonal Regeneration in Adult Glial Deficient Mammalian Spinal Cord

Francis J. Liuzzi, Ph.D.

Bio-Architectonics Center, School of Medicine, Case Western Reserve University, Cleveland, OH 44106

Sponsor: *Paralyzed Veterans of America, Spinal Cord Research Foundation (Proposal NFR-654)*

Purpose—The dorsal roots of the spinal cord are the routes by which information from the skin, muscles,

joints, and viscera reach the central nervous system. This information is essential for spinal reflexes,

somatic and visceral, as well as for the conscious perception of the world around us. The avulsion of dorsal roots, either by injury to the roots themselves, or in concert with spinal cord injury, has grave consequences to the victim. Injury to the dorsal roots that supply the brachial plexus can render the arm a useless appendage devoid of any sensations including touch, pain, and position awareness. More seriously, damage to the dorsal roots of the sacral cord can disrupt vital visceral reflexes that are particularly important in bladder and bowel, as well as sexual function.

For the past 4 years, the P.I. has been studying dorsal root axonal regeneration in the adult frog and in the adult rat spinal cords using horseradish peroxidase (HRP) to specifically label regenerating axons for light and electron microscopic analysis. The regenerative capacity of dorsal root axons had already been well documented in the early part of this century. This work, and that of others, has shown that when the dorsal root is injured, cut or crushed, in either the amphibian or the mammal, the degenerative and regenerative responses in the peripheral portion of the root are exactly the same as those of any peripheral nerve.

However, at the dorsal root transitional zone, the region in which the peripheral nerve environment of the root is contiguous with the central nervous system environment of the spinal cord, there is a dramatic difference between amphibian and mammalian dorsal root axonal regeneration. In the frog, a large percentage of regenerating dorsal root axons

penetrate this region, grow into the cord and restore, in part, the segmental innervation of the gray matter. By contrast, in the mammal, the majority of regenerating dorsal root axons either stop or turn to grow back out into the root. It appears that, in the mammal, astrocytes in this region act in some way to prevent the penetration of regenerating axons into the spinal cord. Although there have been many reasonable hypotheses advanced to explain this enigma, the exact mechanisms by which these astrocytes prohibit dorsal root axonal reinnervation of the spinal cord remains unknown.

Implications—A number of laboratories, including our own, are examining the role of the transitional zone astrocytes in abortive dorsal root axonal regeneration. This work is of the utmost importance in the field of regeneration because it is directed at basic questions about the role of astrocytes in preventing axonal regeneration in the adult nervous system. The impediment of axonal regeneration by the astrocytes of the dorsal root transitional zone are, however, only one aspect of the broader question of axonal regeneration in the adult mammalian spinal cord. Of equal importance are the questions of whether, if the axons were able to gain access to the cord, the environment of the adult mammalian spinal cord is capable of supporting dorsal root axonal regeneration, and, if so, whether the regenerating axons are able to recognize and appropriately reinnervate their targets in the spinal gray matter.

Action and Metabolism of TRH in the Spinal Cord (TBR-463)

Chandan Prasad, Ph.D.

Louisiana State University Medical Center, Section of Endocrinology, Department of Medicine, New Orleans, LA 70112

Sponsor: *Paralyzed Veterans of America, Spinal Cord Research Foundation*

Purpose—TRH ameliorates neurologic consequences of spinal cord injury in cats, suggesting its potential application in man. However, rapid *in vivo* inactivation of exogenous TRH presents a serious obstacle in its effective clinical use. Over the past few years, our laboratory has been actively seeking ways to overcome the above problem. Results of our recent studies, funded by PVA-SCRF, have shown that certain TRH analogues can raise the level of endogenous TRH presumably by inhibiting

its metabolism. We propose to extend the above observation to explore the conditions under which maximal elevation in TRH content can be achieved. In addition, the nature and extent of chemical changes in the spinal cord following TRH elevation will be determined. The chemical parameter selected for investigation will be those that are associated, directly or indirectly, with the process of tissue damage and recovery.

Future Plans—The ultimate goal of our study is to investigate recovery from acute experimental spinal

cord injury using TRH and its analogues that elevate the levels of endogenous TRH in the spinal cord.

International Symposium on Neural Regeneration

Fredrick J. Seil, M.D.

Office of Regeneration Research Programs, Veterans Administration Medical Center, Portland, OR 97201

Sponsor: *Paralyzed Veterans of America, Spinal Cord Research Foundation (Proposal NCR-666)*

Purpose—The purpose of this symposium is to: 1) present current information on research in neural regeneration by some of the world's leading investigators in specific research areas; 2) foster interchange among scientists about research information in an informal as well as a formal setting; 3) provide an opportunity for students and postdoctoral fellows to exchange ideas with senior scientists; and 4) disseminate the information provided by the symposium in the form of a publication of the proceedings. This will be accomplished by holding the symposium at the Asilomar Conference Center, a beachside conference facility run by the State of California, inviting leading researchers to present their work and supporting their travel and per diem expenses, organizing the conference with sufficient free time between formal sessions to allow relaxed interchange, and requiring most of the speakers to write a chapter for the proceedings book as part of their agreement to accept the invitation to partici-

pate. There will also be free communications from registrants at large in the form of posters.

The problem being addressed is the exchange of current information among neural regeneration research scientists and the dissemination of that information to the larger scientific community. The goal is to gather leading neural regeneration research investigators from around the world into one pleasant, quiet place and promote the exchange of information and cross-fertilization of ideas in both formal (scheduled presentations) and informal (free time) formats, and to convey the enthusiasm for this kind of research to students and postdoctoral fellows in attendance. This enthusiasm can be conveyed to a larger audience, both professional and nonprofessional, in the form of a proceedings publication and in lay summaries of the sessions that can be included in the *VA Regeneration Research Newsletter* and *PVA Paraplegia News*.

D. Rehabilitation

Hybrid Upper Extremity Orthoses for C5-7 SCI Patients

Nisim Benjuya, Ph.D., and Steven B. Kenney, BSME

Clinical Bioengineering Lab, Veterans Administration Medical Center, West Roxbury, MA 02132

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—To enable the upper extremity to function independently in spinal cord injury (SCI) patients at the C5-7 levels. The secondary goal is to restore range-of-motion including index-thumb opposition for the purpose of rehabilitation of patients with intrinsic and extrinsic motor dysfunction in the hand. The functions of the orthoses under development will offer pinch grip, lower arm supination/pronation, elbow flexion/extension and shoulder abduc-

tion/adduction. The engineering efforts are concentrated on simplicity, lightness and cosmesis of the device. Electromyography (EMG) from existing muscles, mixed with movements of accessible limbs are used as driving signal sources for our hybrid orthoses.

Progress—For the past year an ongoing effort has been made in developing an "ideal" orthosis system

for the hand. The orthosis contains a hand shell and finger guide, both made of light and rigid material. The unit consists of a 6-volt DC gearmotor located in the palm with a gear train assembly transferring the motor torque to the finger guide. The control system consists of a pair of dry EMG surface electrodes operating as on/off switches and current feedback controlled four channel push/pull driver. The driver sets the hold position to the motor at pre-selected grip forces varying between 1-3 lbs. The whole system is powered by a re-chargeable 6V battery encapsulated in a durable case. The case and circuitry are attached to the body of the user. We are at the stage where the hand orthosis is

undergoing clinical evaluation and testing.

Future Plans/Implications—In the coming year we will develop the elbow and shoulder system. These orthoses should enable the user to function in various daily living activities such as eating, shaving, etc. with minimum effort. The hand system will use a motor controlled by a 3-state proportional EMG detection and a strain gauge-based electrocutaneous pinch force feedback delivered to the patient via a surface electrode. Some other foreseen benefits of the hand orthosis are augmentation of upper extremity strength and coordination through a vigorous post-operative therapy regimen.

Treatment of Physiological Impotence

Inder Perakash, M.D.

Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service (Project #XB299-2RA)

Purpose—This is an interdisciplinary effort directed primarily at assisting several aspects of the sexual rehabilitation of paraplegic patients, and as such involves experts in urology, physiology, biomedical engineering, and rehabilitation medicine. Our research with 46 patients (96 studies) has further sophisticated the technique of rectal probe electrostimulation (RPE) to induce semen collection.

The technique of rectal probe electrostimulation (RPE) has been brought from a stage of trial development of instrumentation to clinical use as a miniaturized, fail-safe device operable by trained health professionals. This unit utilized an isolation transformer with 140 decibels of common-mode rejection, new semi-conductor technology to allow constant current stimulation, and plug-in modular construction. A battery-operated device is also being made available. The equipment is now ready for both clinical evaluation (of erections and emissions, depending upon existing patient sensorium and testicular function), and subsequent treatment or therapy (for physiological impotence or ejaculatory incom-

petence). A comprehensive evaluation, including sexual history, semen gonadotropin (FSH, LH, PRL) and steroid (estradiol, testosterone) hormones, microscopic (TEM, LM) evaluation of testicular biopsy (when applicable), and uroneurologic evaluation will accompany RPE in patient assessment. Equipment modifications and further animal experimentation will be done at Emory.

Goals for year 3 include: 1) identification of 10 additional paraplegic patients as candidates for home-based RPE; 2) clinical evaluation of these patients with initial education in the use of RPE in the home setting; 3) evaluation of success of year 3 paraplegic patients with RPE to produce erections and emissions in the hospital-based "home setting;" 4) introduction of year 3 paraplegic patients to RPE in their home setting; 5) extension of RPE to 5 additional quadriplegic patients, with management of autonomic dysreflexia based upon information obtained by work with year 3 patients; and, 6) continued Foley catheter modifications and semen treatment to improve motility.

Interactive Videodisk Training for Self-Care Skills

John Trimble, Ph.D.; Bernard Nemchausky, M.D.; Mark Ozer, M.D.

Spinal Cord Injury Service, Veterans Administration Medical Center, Hines, IL 60141 and Spinal Cord Injury Service, Veterans Administration Medical Center, Richmond, VA 23249

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—Rehabilitation training is frequently ineffective. The reasons for this are complex and range from people's unwillingness to learn more about their disability to health care professionals who do not have enough time to devote to teaching. The result of ineffective rehabilitation training is rehospitalization which is not only costly but also has a profound effect on the disabled person's quality of life.

There are ways to make rehabilitation training programs more effective. However, these are either marginally successful or costly. Some institutions have tried using videotapes, publications or pamphlets, but there is no evidence that these improve the quality of the training program. Other institutions have attempted to increase the number of personnel involved in rehabilitation training. However, this requires hiring additional personnel or relieving health care staff from their regular duties to give them more time to adequately train patients. As yet, there is no generally acceptable way of improving the quality of rehabilitation education.

We hypothesize that interactive videodisk training, used as an adjunct to traditional methods of rehabilitation education, will enhance the quality and effectiveness of the program. Interactive videodisk training has been used for several years in industry. Although the effectiveness of these applications has not been quantitatively determined, it is agreed that they have increased the effectiveness of training programs.

The few studies done on these applications suggest that the increased effectiveness is directly related to the medium. Like computer-assisted instructional programs, interactive videodisk training gives stu-

dents the opportunity to learn at their own pace. However, unlike computer-assisted instructional programs, interactive videodisk training lets students view highly complex visual material. This feature is especially important when learning skills that are predominantly visual or best learned through visualization. This advantage leads us to study the potential of interactive videodisk training as an adjunct to traditional rehabilitation education programs.

Progress—We have created an interactive videodisk training program on skin care using a videotape developed by the Spinal Cord Injury Service of the Richmond VA Medical Center. We have also developed a stand-alone interactive videodisk training system using commercially available components. Additionally, we have developed software that allows educators with little knowledge of computers to easily develop interactive videodisk training programs. We are presently examining patients' reactions to the new system, and determining the ease with which educators can develop their own interactive videodisk training programs.

Future Plans/Implications—Once we have evaluated the system on a small scale, we will create additional systems and evaluate them on a larger scale with a diverse subject population. We will also develop additional materials for training in wheelchair transfers, genito-urinary care, and bladder and bowel care. We also intend to develop software to analyze the tasks involved in these skills to produce an "expert system" for creating the outlines for interactive videodisk training programs.

Interactive Videodisk Training for Self-Care Skills (Project Extension)

John Trimble, Ph.D., and Bernard Nemchausky, M.D.

Veterans Administration Medical Center, Hines, IL 60141 and Loyola University Stritch School of Medicine, Chicago, IL 60626

Sponsor: VA Rehabilitation Research and Development Service (Project #XB451-R)

Purpose—Instruction in self-care skills is an essential component of the rehabilitation of persons with spinal cord injuries. The importance of this component is evidenced by the fact that between one-third and one-half of spinal cord injured persons are rehospitalized in any given follow-up year. The average annual cost for each rehospitalization can range from \$6,700, if surgery is not required, to \$20,000, if surgery is required. Self-care skills can reduce the incidence of rehospitalization due to preventable complications, hasten progress toward adaptation to the disability, and provide for greater personal independence.

Traditional methods of health-care education such as personalized instruction by a health-care professional, self-instruction from written or audiovisual materials, participation in learning groups, or interaction with other disabled persons are often ineffective. Factors such as the person's psychosocial, economic or educational status; the extent of involvement by health-care professionals; and, the instructional material or methods can all influence an educational program's outcome. Although some of these factors can be controlled and improved, others can not. Accordingly, health-care institutions are faced with the difficult problem of teaching valuable skills to people with diverse socioeconomic backgrounds, attitudes and skills, using staff who may have little time to teach them.

We believe that this problem may be resolved by augmenting traditional education programs with interactive learning technology. Technologies such as computer-assisted instruction (CAI) or interactive-videodisk instruction (IVI) have several advantages as adjuncts to traditional educational methods. People with diverse socioeconomic and educational backgrounds can learn at their own pace. The

novelty of interacting with a computer may provide motivation for learning. CAI or IVI may also be more effective than personalized instruction for teaching difficult or emotion-laden subjects, since they are impersonal and nonthreatening. Interactive learning technologies also free staff to give personalized instruction to people who need it.

Our project will examine the effectiveness of interactive videodisk instruction as a supplement to two traditional rehabilitation education programs. We will develop interactive videodisk material for instructing spinal cord injury persons on self-care techniques for skin care, genitourinary care, wheelchair transfers, and assertiveness. We will also develop and test instruments for evaluating the effectiveness of interactive education in terms of instruction (extent and recency of instruction), cognition (aggregate knowledge of self-care skills), and performance (current practice of self-care skills). We will determine the usefulness of interactive videodisk instruction by comparing the index scores of people who have received traditional instruction and people who have received a combination of traditional and interactive videodisk instruction. We will also develop authoring software that represents a considerable improvement over existing software so that the results of our study may be widely disseminated. The software will allow users to easily develop interactive learning sequences that incorporate motion video, overlay graphics, and questions.

We believe that our study could help spinal cord injured persons achieve greater independence by improving the instruction that they receive to learn the knowledge and skills that they need to lead productive and independent lives.

Man-Machine Interface for Upper Limb Neural Prostheses

William K. Durfee, Ph.D.

Massachusetts Institute of Technology, Department of Mechanical Engineering, Cambridge, MA 02139

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The goal of this project is to improve the functional capability of quadriplegics outfitted with neural prosthesis to return grasp. to achieve this goal we are developing an experimental model to study the man/machine interface between a quadriplegic and an upper limb neural prosthesis. Our plan is to instrument able-bodied and spinal cord injured (SCI) human subjects who will perform simulated tasks by manipulating animated limbs appearing on a graphics display. This will enable us to isolate the command input system of a neural prosthesis from all other extraneous factors such as electrode shift and stimulated muscle fatigue. Using this experimental model, we hope to quantify the ability of subjects to manipulate specific command channels to drive neural prostheses, and identify command channels for particular subjects.

Progress—We have developed a set of graphics routines for an Amiga personal computer which display an animated hand that can translate, rotate,

and open and close under control of external signals. Our first tests will investigate shoulder motion as an input command channel while subjects perform simulated tasks of grasping, moving, and coordinated motion, between two hands. Most C5 and C6 quadriplegics still retain some shoulder motion and several research groups developing neural prostheses for return of grasp use shoulder motion for an input channel. There is a need, however, to quantify the information content in shoulder motion, particularly when both left and right upper limbs are involved as would be the case for bilateral neural prostheses.

Publications Resulting from This Research

Command Channels for Upper Limb Neural Prostheses. Durfee WK, Mariano T, *Proceedings of the 10th Annual Conference on Rehabilitation Technology*, RESNA, San Jose, CA, June 1987.

Determining the Range of Motion and Principal Directions of the Shoulder for Studying Static Shoulder Control with Hand Tracking. Rodriguez SD, *MIT BSME Thesis*, June, 1987.

Artificial Sensory Transducers

M.R. Neuman, Ph.D., M.D.; H. Chizeck, Sc.D.; P.E. Crago, Ph.D.; P.H. Peckham, Ph.D.; R. Riso, Ph.D.
Cleveland Metropolitan General Hospital and Case Western Reserve University, Cleveland, OH 44109

Sponsor: *Neural Prosthesis Program of the National Institute of Neurological and Communicative Disorders and Stroke*

Purpose—Sensors for measuring forces at the thumb or finger pads are being developed and evaluated along with sensors for determining thumb or finger positions through measurement of joint angles.

Progress—Prototype sixty-four element variable capacitance force sensor arrays have been constructed using thin and thick film technology. Each 2 mm square element is separated from its neighbor by 0.5 mm in the 8 x 8 array. Thin film chrome-gold capacitor plates are deposited upon 75 micron thick polyimide substrates. A specially developed silicone elastomer dielectric film is deposited between the plates using thick film screen printing techniques. A hybrid microelectronic circuit to provide isolation

and active shielding has been developed but not yet assembled on the sensor itself. Multiplexors within this circuit allow elements of the array to be addressed individually.

The sensor is operated under the control of a microcomputer that scans the array, linearizes the hyperbolic characteristic of each element and provides an array and graphic representation of the output from each element. Software to minimize cross talk between adjacent elements and to perform elementary edge and shape recognition is under development.

Joint position sensors based upon thin gold film strain gauges on a flexible substrate are also under development. Preliminary film structures measuring

9 x 30 mm or 4 x 20 mm on 75 micron thick polyimide substrates have been fabricated and are being evaluated. Fabric straps allow the smaller gauges to be placed on the dorsal side of a finger. The gauge is affixed to one strap on the proximal side of an interphalangeal joint. The strain gauge structure is able to slide within the second clamp on the distal side of the joint as the joint is flexed. This structure has been designed to give a change in resistance that is dependent only upon the joint angle.

Results—The output voltage as a function of applied force has been studied for each element of the force sensor. Typical sensor characteristics are: element capacitance, 6 ± 1 pF; mean sensitivity, at 0 N is 287 mV/N and at 4 N is 91 mV/N; mean cross talk, 5.13 percent; and refresh time, 0.64 s. The sensors were found to have high temperature coefficients due to the silicone elastomer dielectric. Joint position sensors were studied over angles of 0-100 degrees. Radii of curvature were varied from 5 to

15 mm. Nominal resistance for the gauges was 100 ohms and the characteristics were found to be linear. Mean sensitivities were found to be 1.31 percent/degrees at a radius of curvature of 15 mm and 1.54 percent/degrees at a radius of curvature of 5 mm. Single strain gauges had a high temperature coefficient but this could be compensated using gold film patterns in adjacent arms of the bridge circuit.

Future Plans—Both the force and position sensors are early in their development. Further *in vitro* studies are necessary before the devices can be used on human subjects. The force sensor needs to be temperature-compensated and packaged. The electronic circuitry needs to be placed on the sensor itself and incorporated into the package, and software needs to be refined for obtaining total force and its distribution. The work on developing joint angle sensor structures for placement on human fingers needs to be completed and evaluated *in vitro* and *in vivo*.

Vocational Evaluation for Quadriplegics with a High School Education or Less

W. Alfred, M.A.

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *Rehabilitation Research and Training Center on Spinal Cord Dysfunction; National Institute on Disability and Rehabilitation Research*

Purpose—The project objective is to develop a vocational evaluation process that will expand the vocational options for spinal cord injured persons who are quadriplegic, who have a high school education or less, and who have either a limited work record or a job history incompatible with current functional limitations. Methodology involves: 1) identifying and documenting jobs that can be performed by the described population group; 2) conducting a comprehensive review of existing vocational assessment tools and determining relevance of the tools to assess the potential of quadriplegics; 3) selecting and organizing a meaningful process; 4) incorporating the model vocational process into the Vocational Department's service delivery program; and, 5) evaluating the effectiveness of the model evaluation process.

The expected outcome of this project is the establishment of a more effective and realistic vocational evaluation process that can be used to

assess the job potential of quadriplegics. The project may also have implications for other disability groups with severe physical impairments.

Progress—The developmental phase of the project has been completed. Of 12,278 jobs listed in the Directory of Occupational Titles, 497 were judged by the project staff to be options for quadriplegics with a high school education or less. Labor market surveys were conducted to identify the occupational outlook among these jobs. Findings indicated that jobs in clerical and sales occupations were the largest in demand. The outlook for jobs in machine trades and benchwork occupations was discouraging.

A total of 334 vocational assessment tools were reviewed, and 105 of these tools were determined by the project staff to be within the physical capabilities to be performed by persons with quadriplegia.

Results—The project staff has matched those assessment tools that appear to measure the duties of those jobs that have the best occupational outlook for the future. This has resulted in a vocational evaluation process that includes psychometric testing, work sample testing, simple work modifications, training in compensatory techniques, and limited situational assessment.

Future Plans/Implications—Currently, 20 subjects with quadriplegia are being sought to participate in the vocational evaluation process in order to gauge its effectiveness. In addition, a panel of rehabilitation professionals is assessing the usefulness of the results obtained from vocational evaluation.

Development of a Reconditioning Exercise Program for Patients with Paraplegia

David Cardus, M.D.; W.G. McTaggart, B.S.; F. Ribas-Cardus, M.S.

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *Rehabilitation Research and Training Center on Spinal Cord Dysfunction; National Institute on Disability and Rehabilitation Research*

Purpose—The overall purpose of this project is to develop a testing methodology and to evaluate an exercise training program for the physical reconditioning of the patient with paraplegia. The expected outcome is the formulation of guidelines for the prescription of exercise and the documentation of the effects of physical conditioning programs for the patient with paraplegia. Male paraplegics between 18 and 50 years of age, free from disorders which contraindicate relatively high levels of exercise, and who have reached a suitable status in their rehabilitation process, will be selected for participation in the project.

Each participant will be initially administered an exercise stress test consisting of interviews, blood sample for biochemical analyses, resting ECG, physical exam, and a graded arm ergometry test using an interrupted steady-state protocol. Expired gas will be collected during the last minute of each exercise phase. The training program modalities will consist of prescribed unsupervised exercise at home or exercises in a gamefield especially designed for wheelchair patients. Other patients will perform prescribed exercise under supervision in the laboratory or gamefield. Initially, the exercise period is for 5 to 10 minutes, increasing to 20 to 25 minutes with training. Training will be three to five days per

week for 10 to 12 weeks. After training, the patient will be subjected to a post-training study in which the testing of the first study will be repeated.

Progress—Four arm exercise training ergometers have now been purchased and are being presently utilized in prescribed home training programs. One patient has procured his own trainer and is following a prescribed exercise program at home.

The assessment of the cardiovascular tolerance to physical work with arm exercise has been extended to 33 untrained paraplegic males, some more than one time for a total of 47 tests. In addition, 16 healthy males have been tested in the same manner, a total of 31 tests, for obtaining comparative data. Nine of the paraplegic males and eleven of the healthy males have been tested in the gamefield for evaluation of energy requirements for specific athletic events. To date, eight paraplegic males have been placed on prescribed training at home. Three patients on home programs initially had exercise training in this laboratory with extension of the program at home. Healthy subjects have been tested in the laboratory using leg and arm exercise protocols for comparing the mechanical efficiency of different muscle groups.

Longitudinal Assessment of the Utilization of Upper Extremity Assistive Devices Prescribed for the Spinal Cord Injured Quadriplegic

Susan Garber, M.A., O.T.R. and Theresa Gregorio, O.T.R.

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: Rehabilitation Research and Training Center on Spinal Cord Dysfunction; National Institute on Disability and Rehabilitation Research

Purpose—Upper extremity assistive devices are frequently prescribed during the rehabilitation of spinal cord injured (SCI) quadriplegics. However, though these devices are used daily during hospitalization, they may be discarded once the individual leaves the hospital environment. The primary objectives of this study are to: 1) identify functional categories of assistive devices prescribed for quadriplegics; 2) determine utilization and satisfaction with those devices one year and two years following rehabilitation; and 3) determine factors responsible for discarding devices.

This is a longitudinal prospective investigation in two parts. Phase I of this study is a review of 102 quadriplegics to determine functional categories and frequency of prescription of upper extremity assistive devices. Phase II employs an oral questionnaire of 75 patients to ascertain utilization of, and satisfaction with, devices prescribed during a first rehabilitation experience. This questionnaire is administered one and two years following discharge.

Satisfaction is determined using a Likert scale. It addresses the device characteristics of fit, cosmesis, mechanical, and functional performance. Factors that result in discarding a device include improved physical function, mechanical failure, alternative solutions, modification of living arrangements, non-compliance, and device outgrown or unattractive.

Progress—To establish the functional categories and frequency of prescription of upper extremity assistive devices, 102 charts of quadriplegic patients were reviewed. Feeding devices were prescribed to 49 percent of patients, splints and slings to 87 percent, dressings to 30 percent, hygiene/grooming to 22 percent, and communication devices to 20 percent. An oral questionnaire developed to determine device utilization and level of satisfaction was administered to 77 former patients one year following their first rehabilitation experience. For these patients, 262 devices had been prescribed. Sixty-seven devices were for feeding. One hundred and

sixteen patients received splints and slings; 18 received dressings; 19, hygiene/grooming; 17, communication; and 8, miscellaneous. At the end of one year, 151 devices (58 percent) were still in use (36, feeding; 75, splints and slings; 7, dressings; 8, hygiene/grooming devices; 17, communication devices; and 8, miscellaneous). On a scale of 1-5 (5 being the most satisfactory), those devices still in use were rated an average of 4.24. The most frequently cited reasons for discarding devices were improved physical function and alternative solutions found. Discarded devices represented a cost of \$5400 or 35 percent of the total expenditure for all devices.

Of the original population, 55 were queried two years post-rehabilitation. Of the devices prescribed during their first rehabilitation experience, 69 percent were still in use two years later, with an overall level of satisfaction of 4.35 with retained devices. Of the remaining 22 subjects from the original population, 20 could not be reached by mail or telephone, one was too disoriented to respond, and one had expired.

The overall costs of devices prescribed for subjects during their hospitalization were \$17,831. The costs of devices discarded during the first year following rehabilitation were \$5,860 or 32 percent of the total expenditure. The costs of devices discarded during the second year were \$2,877 or 31 percent of the total cost of devices in use.

Preliminary Results—The results of this study already have influenced some of the prescription practices within the occupational therapy department. Therapists consider less expensive short-term devices rather than ordering the most expensive models of the same item. Furthermore, the Occupational Therapy staff is relying more on department-owned equipment from which patients may be weaned prior to discharge. Data on specific devices are being scrutinized to establish practical guidelines for their continued prescription.

Future Plans/Implications—An addendum to the original proposal has been written, the purpose of which is to collect data on a device only recently introduced to the population of persons with quadriplegia. This device is a passive stabilizer of assistive devices as opposed to the reciprocal orthosis (wrist-driven flexor hinge) which requires active wrist extension to achieve fine prehension. This

study will have both financial and professional implications. These include relative costs of the two devices and custom versus ready-made fabrication. The investigators will address the issues of utilization and satisfaction with the newer device using the same methodology employed in the original project.

Longitudinal Assessment of Physical Therapy Factors in the Rehabilitation Process That Affect the Quality of Life of Persons with Spinal Cord Injury

L. Don Lehmkuhl, Ph.D.

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *Rehabilitation Research and Training Center on Spinal Cord Dysfunction; National Institute on Disability and Rehabilitation Research*

Purpose—The primary objectives of this study are to: 1) determine the importance of the patient's compliance in performing weight-shifts in a wheelchair to prevent breakdown of skin in weight-bearing areas of the body; 2) improve the criteria and procedures for selecting which spinal cord injured patients should be braced and trained to become functional ambulators; and 3) determine the incidence, characteristics, and outcome of pain complaints in patients with severe spinal cord injury.

Progress—Reduction in the original level of funding necessitated reduction in the scope of the project being undertaken. Considering the resources and expertise available, we elected to defer action on objective 1 and concentrate on objectives 2 and 3. As we complete work on objectives 2 and 3, we will redirect staff effort to pursue objective 1. Patients being studied are individuals who have received severe injuries to their spinal cord resulting in paraplegia or quadriplegia.

A total of 70 patients between the ages of 20 and 58 years with paraplegia have been studied in pursuing objective 2. A list of patient attributes and equipment and services associated with the gait training program was compiled for each patient. Follow-up evaluations, six months to several years after bracing, are being made to assess brace utilization. We expect the results to improve the criteria for selection of those who will remain users of braces.

A total of 135 patients between the ages of 11 and

80 years (74 with quadriplegia and 61 with paraplegia) are being studied in pursuing objective 3. Information on pain status, method of treatment, and reported success of treatment is gathered on a weekly basis until time of discharge. We expect the results to illustrate trends in etiology and resolution of pain complaints. An additional 35 patients are participating in a prospective study of the effectiveness of specific therapeutic interventions in relieving specific types of pain complaints.

Preliminary Results—Thus far we have: 1) analyzed the results of brace utilization by 70 patients who received bilateral knee-ankle-foot orthotic devices and drafted a report of the findings; 2) begun pilot studies with an orthotist to devise a simplified, modular lightweight orthotic device for early bracing and gait training; 3) gathered and categorized data concerning the pain complaints made by 135 patients with spinal cord injury during their initial hospitalization for comprehensive rehabilitation; 4) examined correlations between population variables, etiology of injury, level and neurological completeness of injury, and location and suspected etiology of pain complaint; 5) documented the status of each pain complaint at the time of discharge; 6) identified therapeutic procedures that patients reported as most effective in alleviating individual pain states; and 7) initiated a prospective study (N presently = 35) designed to test the relative effectiveness of specific therapeutic interventions in alleviating particular types of pain.

Future Plans/Implications—We are preparing final reports of the results obtained from pursuing objectives 2 and 3. Articles describing our findings are

being prepared for submission to *Physical Therapy* and the *Journal of the American Physical Therapy Association*.

Documenting and Utilizing Programs Which Provide Community Adjustment and Independent Living Services for Persons with Spinal Cord Injury

Margaret A. Nosek, Ph.D

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *Rehabilitation Research and Training Center on Spinal Cord Dysfunction; National Institute on Disability and Rehabilitation Research*

Purpose—The purpose of this project is to collect and maintain information about independent living and community adjustment programs that serve spinal cord injured people, to provide an effective means of communicating new ideas and experiences between individuals operating these programs, and to provide access to a dependable source of technical assistance related to these programs.

Progress—Nonexperimental survey methodology is being used. The data from earlier administrations of this survey were summarized in frequencies according to specified categories of interest, and some correlational studies were done to determine trends in independent living program development. Data from project surveys was used to assess the types of services being provided for persons with spinal cord injury, and the source and amount of funds being utilized. The survey instrument has been revised, expanded, and pilot-tested. It will be readministered to all identified independent living programs. Data will be analyzed using univariate and multivariate techniques and will be compared to earlier findings.

In order to facilitate use of the information which is developed, the project maintains a computerized bulletin board, a telephone communication network with all the extant independent living programs, and a mailing list of approximately 2000 additional individuals and organizations. Knowledge transfer strategies depend on the specific topic or sets of information, but they usually involve extensive reviews of existing literature, interviews with independent living program administrators, staff members, consumers, and supplementary reviews by additional experts both in and out of the independent living field.

Preliminary Results—The 1986 administration of the survey yielded a 70 percent response rate (166 programs) with 51 percent (54 programs) providing complete data. All data have been entered into the ILRU National DataBase on Independent Living Programs. Extensive analysis is being conducted to examine a broad array of variables related to the delivery of independent living services to persons with spinal cord injury. Preliminary results indicate that persons with spinal cord injury are served by 80 percent of independent living programs, an increase of one percent from 1984. Of programs meeting the criteria for independent living centers, 95 percent report serving this population. Further investigation into the significance of the "center" model is being conducted.

Future Plans/Implications—In addition to data runs and reports in response to specific inquiries, there have been many products from this study to date. Two major presentations and two poster sessions on the preliminary results have been given at four national conferences to date. The Directory of Independent Living Programs has been updated and reissued five times in the past year. The new Registry of Independent Living Programs is near completion, and will go to press in early July. By the end of the year, a third major publication will be completed, analyzing the longitudinal database in relation to services to persons with spinal cord injuries and discussing policy implications of the findings.

The ILRU project is continuing its training, networking, and information dissemination activities in the area of independent living and maintains an ongoing effort to update its databases.

Assessment, Development and Clinical Applications of Strategies to Coordinate Services for Spinal Cord Injured Clients After Discharge

D. Rintala, Ph.D.; J. Alexander, Ph.D.; E. Willems, Ph.D.

Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *Rehabilitation Research and Training Center on Spinal Cord Dysfunction; National Institute on Disability and Rehabilitation Research*

Purpose—There are three major project objectives: 1) assess current strategies employed after discharge, to achieve psychosocial adjustment and productive lives for spinal cord injured (SCI) persons; 2) develop and test new strategies or refine current strategies to enhance outcomes postdischarge; and 3) facilitate the integration of new and tested strategies into the service delivery system at The Institute for Rehabilitation and Research (TIRR) and disseminate the strategies to other appropriate sites. Methods include interviewing rehabilitation professionals and spinal cord injured clients to assess needs and resources, collaborating with service providers to develop and test improved strategies to address unmet needs, and assisting integration of the improved strategies into the service delivery system. Approximately 150 spinal cord injured persons over 14 years of age who were admitted to TIRR for comprehensive rehabilitation from 1979 to the present will be interviewed. Rehabilitation professionals from a variety of disciplines will be interviewed and/or serve as an advisory committee.

The benefits expected from this project include meeting needs early to avoid compounding problems, utilizing resources efficiently by tailoring programs to meet the actual needs of clients, and improving rehabilitation outcomes by providing appropriate services.

Progress—A protocol was developed for interviewing rehabilitation professionals. Eight professionals from six rehabilitation disciplines were asked to describe the needs of SCI clients following discharge, the resources available to meet those needs, and the systems for linking the clients with the appropriate resources. Eight broad categories emerged: Health, Activities of Daily Living, Living Arrangements, Vocational, Psychosocial, Transportation, Financial, and Societal Issues and Policies.

The list of needs described by the professionals was used to develop an interview protocol for use with clients to determine needs, utilization of formal and informal resources, links, resources, satisfaction with resources, and special difficulties encountered in meeting their needs.

Preliminary Results—One hundred and fifty interviews have been completed from a pool of approximately 600 eligible clients. In the first of two sets of preliminary analyses, needs that were identified included: a) further efforts aimed at preventing urinary tract infections and pressure sores; b) professional attendant care services and the resources to pay for them; c) postdischarge psychosocial services for clients and their families; and d) efforts to overcome the additional handicaps experienced by females, blacks and Hispanics as compared to males and whites.

Findings from the second set of analyses included: a) psychosocial services need to be individualized and they need to be offered to both parental and marital family members as well as to the spinal cord injured client; b) gender and marital status must be carefully considered when planning and implementing services and when formulating expectations regarding appropriate outcomes; and c) available resources have not been utilized as often as they might be and client satisfaction with those that are used leaves room for improvement.

Future Plans/Implications—We are working collaboratively with the National Spinal Cord Database and the RTC project on Outcome Studies Pertinent to the National Model Spinal Cord Injury System. Requested preliminary data has been shared with the Medical Director, outpatient clinic, and vocational department.

V. Wheelchairs and Powered Vehicles

A. General

Evaluation of the Neutral Posture for Handicapped Utilizing Wheelchairs

Michael Krebs, M.D. and Jerome J. Congleton, Ph.D., P.E.
Texas A&M University, College Station, TX 77843

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objective of this project was to build and fit the neutral posture chair to three wheelchairs (Amigo, Everest/Jennings, and Alexis). The neutral posture chair is a unique combination of a forward sloping cultivator seat and an English saddle, with wrap-around leg trough support.

Progress/Methodology—1) *Modify and install a neutral posture chair to fit existing Amigo hardware.* The chair provided pneumatic adjustment of height and, while seated, adjustment of seat pan tilt and backrest angle and included a manual lock to stop seat rotation when desired as well as optional armrests. The handle bars and steering post were modified to allow greater leg clearance, provide bend in steering post, and provide speed control linkage to handle. A deflector guard was developed for the dual rear wheels.

2) *Modify Everest/Jennings wheelchair and neutral posture chair for compatible attachment.* A modified wheelchair that can be collapsed and stowed in the rear seat of a vehicle by the user was provided. A Pos-chair with adjustment of independent seat pan and back rest tilt angle as well as armrest controls for actuation of seat pan and back rest tilt mechanisms was provided. Materials and design modifications to reduce overall weight of chair was

investigated.

3) *Modify Alexis wheelchair and neutral posture chair.* A Pos-chair was designed with electrical height and tilt actuation and a seat pan and back rest bladder system. The mounting hardware on the wheelchair was redesigned to accommodate the new Pos-chair interface and the armrest with control assembly and footrests was added.

Preliminary Results—The prototype of the neutral posture chair for the Amigo is complete and user evaluation and feedback began in July, 1987. The prototypes for the Everest/Jennings and Alexis wheelchairs were completed and the user evaluation/feedback began in August, 1987.

Future Plans/Implications—Assuming user evaluation/feedback is positive and considerable advantages can be obtained, additional funding will be sought. The neutral posture designed wheelchairs will then be compared to currently utilized wheelchairs. The scientific methods utilized will be: buttocks and thigh pressure measurements, stability of the chair and person (by measuring center of gravity), anthropometric measurements for work-place design criteria, and measuring the effect of body posture on force-generating capability.

Wheelchair Graded Exercise Test for Patients with Lower Limb Disabilities

W.E. Langbein, M.S.; D.K. Murdock, M.D.; C.J. Robinson, D.Sc.; M.H. Hwang, M.D.; B.A. Nemchausky, M.D.; R.D. Wurster, Ph.D.; L. Kynast

Hines Veterans Administration Hospital, Hines, IL 60141 and Loyola University School of Medicine, Maywood, IL 60611

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Wheelchair locomotion even under ideal environmental conditions can result in elevated levels of exertion and fatigue. For some elderly persons, and patients with cardiovascular and/or pulmonary impairments, manual wheelchair locomotion may pose a significant health risk. If health care professionals must make judgments regarding a patient's capacity to endure the exertional stress of operating a manual wheelchair, give exercise prescriptions for rehabilitation and/or develop aerobic conditioning regimens, they must have appropriate measurement tools for patient evaluation.

The problems addressed in research are to: 1) develop a device that will utilize the patient's own wheelchair for graded exercise testing and aerobic fitness training; 2) establish standardized maximal and submaximal wheelchair graded exercise tests to accurately measure the cardiorespiratory fitness of patients who are restricted to the manual wheelchair; 3) evaluate the sensitivity of the testing system for detecting abnormal cardiovascular and pulmonary responses to exercise stress in spinal cord injured (SCI) and other persons with lower limb disabilities; and, 4) compare wheelchair experimental testing protocol test data against data obtained from conventional arm crank ergometry.

Progress—New experimental graded exercise test protocols are being designed and empirically evaluated. These tests are analogous to the well established procedures for lower limb exercise testing, ie., bicycle ergometer, treadmill. Because the intensity of exercise on the Wheelchair Aerobic Fitness Trainer can be controlled it is possible to test patients with very low to very high exercise tolerance. The WAFT graded exercise protocols to be evaluated are: a) sub-maximal, b) maximal discontinuous, c)

maximal continuous for the highly physically fit, d) maximal continuous for the average fit, and e) maximal continuous for the low fit and those at high risk of coronary heart disease. Exercise tests administered on the WAFT, in accordance with the established protocols, can provide valid and clinically useful information regarding the locomotor performance capacity and cardiorespiratory fitness of SCI patients and others with lower limb disabilities.

Project tasks include: 1) recruitment of an adequate sample of subjects; 2) complete modifications to the WAFT; 3) hire cardiac nurse with current certification in advanced life support; and, 4) continue laboratory bench testing of the WAFT to establish the work done by the user at different velocities and magnetic resistance settings.

Preliminary Results—A prototype device called the Wheelchair Aerobic Fitness Trainer (WAFT) has been constructed and undergone pilot testing. The WAFT was developed and is being evaluated by the Rehabilitation, Research & Development Center, Edward Hines, Jr. Veterans Administration Hospital, Hines, Illinois. This device enables the patient to use his or her own wheelchair as a means of exercise. Thus graded exercise testing on the WAFT can give a more realistic evaluation of a patient's functional capacity for wheelchair locomotion than alternative modes of exercise. The exercise stress test protocols to be utilized in this research project were explicitly created for the WAFT. The concept of task specificity as applied to wheelchair locomotion has been of paramount importance in the development of both the testing device and the graded exercise test protocols.

Ergonomics of Manual Wheelchair Propulsion

R.H. Rozendal; L.H.V. van der Woude; H.E.J. Veeger

Department of Functional Anatomy, Faculty of Human Movement Sciences, The Free University, Amsterdam, The Netherlands, 1007MC

Sponsor: *Innovative Research Programme/Aids for the Handicapped*

Purpose—Manual wheelchair propulsion is less efficient (8 percent) than other ways of human ambulation (e.g., cycling, 25 percent). The nature and causes of this apparent drawback have to be understood if optimization is to be realized.

The objective of the present research is to analyze the driver-wheelchair interface in search of kinesiological, biomechanical, and exercise-physiological aspects of wheelchair propulsion on a straight trajectory and on the dependence of driver, wheelchair, and interface-related variability.

Progress—Wheelchair types were tested on a motor driven treadmill: lever- and crank-propelled wheelchairs proved to be more efficient and less energy-costing than normal hand-rim propelled wheelchairs. A special racing wheelchair appeared the least efficient (7.5 percent max). However, cardio-respiratory responses, frictional losses due to rolling drag, and air resistance were lower. Hand-rim diameter

was of importance; the smaller rims leading to more efficient driving. Physiological responses and movement technique in propulsion depended on power output (velocity, resistance) and on interface factors, such as seat height and shoulder position. Speed adaptation in hand-rim wheelchair propulsion occurred primarily by adapting cycle-frequency, push-duration, and work/push. Duration of the recovery phase showed only a minor decrease, whereas the push range remained constant.

Future Plans/Implications—A wheelchair simulator will become available in late 1987. It will be computer-controlled, with dual controls and simulation systems for asymmetric driving. Force transducers in the propulsion system, as well as the seat and back rest, will enable a more thorough biomechanical analysis. Movement registration and EMG will complete the kinesiological analysis.

A Model for Optimization of Wheelchair Lever Propulsion

Clifford E. Brubaker, Ph.D. and Pradip N. Sheth, Ph.D.

University of Virginia Rehabilitation Engineering Center, Charlottesville, VA 22903

Sponsor: *National Institute on Disability and Rehabilitation Research; Field-Initiated Research Program*

Purpose—The purpose of the project is to develop a model to predict and simulate optimum wheelchair propulsion performance, from dimensional variables and a limited number of performance factors, for wheelchair users. A necessary and more fundamental goal is the development of a model to predict individual force vectors for selected muscles of the upper extremity during a motion cycle.

There are four components of the project. These include: 1) the determination of architectural models for the selected upper-extremity muscles; 2) the acquisition of kinematic, force, and muscle-activation data for a range of wheelchair propulsion cycles; 3) the formulation and evaluation of load-sharing algorithms for the muscles during motion cycles;

and, 4) the development of software for mathematical and graphical simulation and prediction.

Progress—Progress has been made in the first three of these areas. Data from cadaver dissections to determine volume, belly length, pennation angle, optimum fiber length, and length and volume ratios relative to segment lengths and joint-to-muscle attachment distances have been obtained for eight upper-extremity muscles. These data are being compared with measurements acquired from MRI scans.

The development of the architectural model is based on the work of Woittiez et al., in the Netherlands. A 3-dimensional skeletal-link model based on kinematic data has been formulated using IMP,

a CAE software system for linkages and mechanisms. The initial model included 4 d.o.f. and 2 segments. This model is currently being extended to include motion for 5 segments (trunk, scapula, arm, forearms, and hand) with compatible d.o.f. for the involved joints. IMP is being used to formulate the equations of motion for the skeletal link model.

The IMP system has also been used to drive the link model through wheelchair propulsion cycles to calculate the mechanical advantages of the different muscles over a cycle. These data will eventually be used, along with the architectural model, to formulate the algorithms for prediction of the individual muscle force vectors.

Preliminary Results—The results obtained to date are of a preliminary nature. Dissections have been limited to two cadavers; however, the results from comparison of measurements of lengths and volume from the MRI scans with direct measurements obtained by dissection have been quite good. Mechan-

ical advantages for simulated muscles (line forces) have been quantified as a function of joint torques about the shoulder and elbow axis in a preliminary model using the IMP system.

Future Plans—The activities to date represent less than 1 year of work on a 3-year project. More data will be collected to obtain representative values to establish ratios for the architectural model variables for the selected muscles. One task to be performed during the next period is the evaluation of several load-sharing algorithms, based on optimum control theory, that have appeared in the literature. This evaluation will be accomplished using kinematic and EMG data obtained during simulated level propulsion.

Publication Resulting from This Research

A Spatial Musculoskeletal Model for Wheelchair Lever Propulsion. Sheth PN, Brubaker CE, *Proceedings of the 10th Annual RESNA Conference* 7:486-488, San Jose, CA, June 1987.

Functionality and Durability of Manually-Propelled Wheelchairs

R.H. Rozendal; L.H.V. van der Woude; M.E. Roebroek

Department of Functional Anatomy, Faculty of Human Movement Sciences, The Free University, Amsterdam, The Netherlands, 1007MC

Sponsor: *Research Programme on Quality and Functionality of Aids for the Handicapped*

Purpose—The purpose of this study was to analyze individual complaints and appreciations regarding manually-propelled wheelchairs under daily use conditions, related to impairment, intensity of daily use, and wheelchair brand and type.

Progress—Instruments developed for the whole sample were: a telephone questionnaire (180 items) taken twice, a failure-diary kept during a nine-month interval between interviews, and an activity-diary during a week in Spring 1987. In 10 percent of the respondents, a technical examination of the wheelchair, and an odometer mounted to the rear wheel of the wheelchair during a nine-month period, were administered in order to validate the instruments. Samples were drawn from populations of wheel-

chairs provided in 1982, 1983, and 1984 by the two major social welfare corporations in this country. Non-response amounted up to 75 percent or more, resulting in a total sample of N=609 respondents for the first telephone questionnaire.

Progress—Testing is well under way and was to be completed in the Fall of 1987.

Future Plans/Implications—The research will give answers to questions formulated, in as far as the combinations of the variables will result in a considerable number of different cases; contribute to the methodology of this type of consumer research; and provide a basis for realistic and valid lab tests on wear and tear of wheelchairs.

Development of a Motorized, Adjustable Standing Frame

P. Bowker, Ph.D. and A.B. Liggins, M.Sc.

Department of Orthopaedic Mechanics, University of Salford, Salford M5 4WT, UK

Sponsor: *University of Salford Venture and Enterprise Fund*

Purpose—For handicapped, as for able-bodied children, the erect weightbearing position has immense advantages in maintaining health, compared with the sedentary posture. For children for whom walking or standing is impossible or difficult, the weightbearing position can be obtained through the use of a standing frame in which the child is held by three-point support in front of the knees and chest and behind the buttocks. Understandably, however, the daily standing session is not welcomed by these children, who see it as twenty minutes of boring, wasted time, during which they are deprived of the mobility of their electric wheelchair. The objective of this project was, therefore, to produce a motorized standing frame which combined the mobility of the electric wheelchair with the therapeutic value of the standing frame.

Progress—To date, a prototype suitable for children in the age range of 6-11 years has been designed, built, and subjected to trials with a group of handicapped children.

The prototype device consists essentially of a simple standing frame, which can be swung into the horizontal position to facilitate the fitting of the child, mounted on a motorized base. This base carries two twelve-volt traction batteries, which

differentially drive two motors slung behind its rear wheels. Control is via a joystick mounted on a pivoted arm, which gives a top speed of 3.5 mph. All the components of the drive and control systems are standard electric wheelchair parts, which enables a system of proven quality to be assembled at minimum cost. The batteries and motors have a protective cover, featuring lights which flash when the batteries are in need of charging. The detachable table is suitable for schoolwork, for toys or games, or for feeding.

Preliminary Results—The frame has recently been tested with four children at a school for the physically handicapped, and although a number of detail deficiencies were highlighted, the overall concept and execution were found to be most successful. Indeed, that the device had achieved the aim of combining the mobility of the electric chair with the therapeutic value of the standing frame, was confirmed when the children who tested our prototype christened it, "The Stand-up Wheelchair."

Future Plans—We now plan to build a pre-production model, making use of the experience gained with the prototype and improve the engineering of the main structure of the frame.

Development of a Protective Foot and Leg Guard for Use in Wheelchair Sports

S. Naumann, Ph.D., P.Eng.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: *Variety Village Sport Training and Fitness Centre, Toronto, Canada*

Purpose—This study had the following objectives: 1) to gather information on participation of the adolescent and teenage wheelchair population in sports activities; 2) to develop a guard which protects the lower legs and feet of adolescent and teen-aged athletes while playing wheelchair sports; 3) easily attaches to and detaches from a variety of wheelchairs; and 4) will be manufactured at a reasonable cost.

Progress—A survey was conducted of children who characterize the subject population of this project. Information from the questionnaires served to clarify the design criteria by identifying the cause and nature of injuries experienced by children playing various sports, their attitudes toward participation, and the potential for injury.

The guard is a rigid U-shaped structure, protecting but not touching the shin and calves of the child's

legs. It is constructed of a tubular aluminum frame into which is fastened a polyethylene sheet. (Different colors of polyethylene could be used to designate different teams.) Prototypes of the guard have been produced and evaluated for electric wheelchair floor hockey and manual wheelchair basketball.

This project has proceeded through the combined efforts of Variety Village and the Rehabilitation Engineering Department at the Hugh MacMillan Medical Centre. The need was first identified by the staff at Variety Village, who, with their clients, contributed design input and tested and evaluated the guards. Design development and prototype construction has been carried out at Hugh MacMillan Medical Centre.

Preliminary Results—Sixty-eight amateur athletes were surveyed; thirty-seven in manual wheelchairs and thirty-one in electric wheelchairs. Only occa-

sional minor injuries (bruises) have been experienced and/or observed by the players, despite frequent collisions. Concern over potential injury to themselves (including other parts of their bodies) was expressed by nineteen respondents. Game trials showed that the necessary shape of the guard caused some limitations in the player's vision and movements. As well, the athletes indicated a general resistance to the imposition of more protective equipment in their game. This is consistent with the low incidence of injury and the lack of concern for injury by the majority of players. From the results, it was determined that the provision of a guard to provide physical protection is not necessary.

Future Plans/Implications—Future efforts should focus on the development of new equipment and games which have a low risk of injury inherent in them in order to encourage greater participation in wheelchair sports.

Testing of Gel-Electrolyte Batteries for Wheelchairs

William E. Fisher, Ph.D.; Rob E. Garrett, B.Tech.; Barry R. Seeger, Ph.D.

Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: *None Listed*

Purpose—The charge capacity of a liquid-electrolyte lead-acid battery can be determined by measuring the electrolyte density using a hydrometer, but this is not possible with gel-electrolyte batteries. Consequently, test equipment was needed to measure the charge capacity of gel-electrolyte batteries.

Progress—A simple test rig was developed to measure the capacity of the gel-electrolyte batteries used to power wheelchairs. It has been shown that discharge testing with a simple resistive load is a good indicator of battery performance when fitted to a wheelchair. Our battery tester comprises a resistive load, a timer, and a box housing the control switches and electronics. The system was designed to be

simple to operate and suitable for use in a wheelchair maintenance workshop.

Preliminary Results—Results of 166 tests revealed a wide scatter of battery life with different users and also showed that, in many cases, the two batteries used in a wheelchair became unequal in charge capacity after some time in use. It is recommended that pairs of batteries should be charged in series to overcome this problem. A scientific paper describing the test rig and our results has been accepted by the *Journal of Rehabilitation Research and Development* for publication in Vol. 25(2), Spring, 1988.

B. Powered Controllers

UNISTIK Vehicle Controller: Safety, Reliability and Human Applications

Catherine W. Britell, M.D.

Spinal Cord Injury Service, Veterans Administration Medical Center, Seattle, WA 98108

Sponsor: VA Rehabilitation Research and Development Service

Purpose—A control system (the UNISTIK Vehicle Controller) has been designed to enable people with high quadriplegia and limited extremity function to drive a motor vehicle. In this study, engineering safety and reliability testing has been done on the system installed in a van. Engineering testing included lifetime testing of all servomechanisms and extended testing at elevated temperatures of the steering servomechanism. A flexible driver station for training and evaluation was developed and installed. Clinical evaluation of the van will be done in order to identify the types of disabled individuals who would benefit from the Controller and to create guidelines for evaluating and training prospective users of the Controller.

Progress—Engineering safety and reliability testing included lifetime testing of all servomechanisms and extended testing at elevated temperatures of the steering servomechanism. Following the tests, the servomechanisms were disassembled and checked for wear. Extensive road testing included simulated failures of van and controller subsystems. Clinical testing will consist of training 20 - 30 participants in the use of the system. Participants will be high-level

quadriplegics, amputees, post-polio individuals, and individuals with cerebral palsy and muscular dystrophy. Training will include preliminary evaluations, in-vehicle instruction and on-road driving skills and will be done at the Seattle VAMC.

Preliminary Results—Results of engineering safety and reliability testing showed servomechanisms withstood lifetime and temperature testing. No excessive wear was found on gears or bearings in the servomechanisms. Simulated failures of van and controller subsystems produced predicted and reliable responses and proved the effectiveness of back-up systems for braking and steering.

Future Plans/Implications—The van will be clinically tested at the Seattle VAMC. Results from clinical testing and engineering safety and reliability testing will be incorporated into a production model of the UNISTIK Vehicle Controller system. Clinical testing will also identify who would benefit from the controller and define guidelines for training prospective users of the UNISTIK Vehicle Controller system.

Ultrasonic Head-Controlled Wheelchair and Interface

David L. Jaffe, M.S.E.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Center Core Funds; Paralyzed Veterans of America

Purpose—The Ultrasonic Head Control Interface (UHCI) is a device designed to provide severely disabled individuals (quadriplegics) with a means of controlling devices such as wheelchairs in a socially acceptable and aesthetically pleasing manner.

Progress—In order to perform some tasks independently, severely disabled individuals must find communication pathways to replace the ones that

have been totally lost or amplify the ones that are impaired. High-level quadriplegics have a particularly difficult time in replacing lost or diminished channels to the outside world since many of them can only control muscles at their neck level and above.

In this project, two Polaroid ultrasonic distance-ranging sensors are the basis for a new type of human-machine interface. They emit inaudible high-

frequency sound waves which propagate through the air until reflected by an object. A portion of the signal incident on the object is reflected as an echo and is detected by an electronic system. The elapsed time from transmission of the signal to the reception of its echo is proportional to the round-trip distance from the sensor to the object. In this rehabilitation application, two separated sensors are directed at the user's head. The two resultant distance ranges, one from each sensor to the head, and the fixed distance between the stationary sensors, describe a triangle whose vertices are the two sensors and the user's current head position. A geometric relationship allows the offset from the base line and center line of the two sensors to be calculated. This information is then used to map the user's head position onto a two-dimensional control space. The array of distance ranging sensors can monitor the head position of a severely disabled quadriplegic operator to obtain command and control information for the operation of mobility, communication, and robotic devices.

In operation, the user of an UHCI merely tilts the head off the vertical axis in the forward/backward or left/right directions. The translation of head position information into electrical signals can mimic the output of a joystick. Both can be used to control devices to which they are attached, such as a wheelchair, a communication aid, a video game, or a robotic arm.

The main advantage of this type of interface is that no mechanical contact between the sensors and the user's head is required. This effectively separates the user from the device being controlled. With this unit, the user does not feel confined as with devices in close proximity to the face or body, as frequently occurs with other interfaces. He/she would therefore not feel "wired-up" using it; an important factor in its acceptance. The use of the remote sensing ability of the UHCI should result in rehabilitation devices that are socially acceptable and cosmetically pleasing.

Preliminary Results—UHCI have been installed on two electric wheelchairs. The first is an E&J model 3P equipped with a reclining Recaro seat and is in use in France by a quadriplegic woman. The second is mounted on an Invacare Rolls IV with a Solo Products Power Pack and is being evaluated by spinal cord injury patients at this facility.

Both units have been operational since June, 1983. User evaluation has been performed with ten quadriplegic individuals. After a short demonstration and training session, they were transferred into the chair and most were able to successfully navigate the chair without problems. Users stated that they preferred the ultrasonic head control to the chin-controlled joystick wheelchairs that they had used. The device has proven to be easy to use. Its intuitive operation requires little focused concentration and thus does not result in user fatigue.

A generalized interface for a robotics application has also been developed. As with the UHCI, the robot user will be able to select tasks and control the operation of a mobile robotic arm via head position. Specifically, the vehicle's navigation path will be under the control of the user—its trajectory being "drawn" on a CRT with head motions.

A technical manual documenting the work on the UHCI, including background material, electronic schematics, computer program listings, explanations, and illustrations has been compiled. Its intended purpose is to provide information that would allow a technically knowledgeable and adequately equipped engineer to construct a duplicate UCHI and apply it to the control of devices such as powered wheelchairs. This manual has been made available to over fifty interested investigators around the world who are considering the UHCI for research or commercialization.

Future Plans/Implications—Within the VA, a Request for Evaluation has been submitted to the Evaluation Unit and approved. The funds for the production of four commercial prototype units have been received. A solicitation has also been published and a manufacturer is about to be selected from the responses. The delivery of the four units is expected one year after the award of the funds. These devices will then be evaluated at VA Medical Centers throughout the country. Finally, a decision will be made regarding the prescription of electric wheelchairs using the UHCI technology for appropriate severely disabled veterans.

Current Publications Resulting from This Research

- Polaroid Ultrasonic Ranging Sensors in Robotic Applications.** Jaffe DL, *Robotics Age*, March, 1985.
- Human-Machine Interfaces.** Jaffe DL, *IEEE Short Course on Rehabilitation Engineering*, Palo Alto, CA, February, 1986.

A Study of Powered Wheelchair Controllers

Mark Hartridge, M.I.E. Aust.; Barry R. Seeger, Ph.D.

Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: Channel 10 Children's Medical Research Foundation of S.A.

Purpose—The number of children using electric wheelchairs has increased rapidly. New types of wheelchair controllers permit alteration of the wheelchair response to user-input by limiting the wheelchair acceleration and by filtering the user's input signals in various ways. However, the extent of driving improvements, if any, has not been objectively demonstrated. With the provision of independent adjustments for acceleration and signal filtering, a practical problem arises in determining which combination of settings will give the best wheelchair control for a particular user. On current commercial products, wide ranges of acceleration and filter settings are provided, as well as an adjustment for maximum speed. At present, we are unaware of any information which could assist in

identifying combinations of settings likely to help the driving ability of various types of users. Such information would be valuable in assisting wheelchair users and therapists to optimize driving ability, and also in assisting manufacturers to improve the internal software of their controllers, thus providing more effective products for wheelchair users.

The aims of this study are: 1) to determine if new concepts in electronic wheelchair control are effective in improving wheelchair driving performance of children with cerebral palsy, and to quantify any improvements; and 2) to establish procedures for adjusting controllers to obtain optimum driving performance. The outcome will be a protocol for establishing optimum controller settings in order to maximize benefits to users of electric wheelchairs.

The Development and Clinical Assessment of a Universal Wheelchair Controller System

M. Milner, Ph.D., P.Eng., C.C.E.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: The Easter Seal Research Institute, Toronto, Canada

Purpose—This study has the following objectives: 1) to develop a closed-loop wheelchair controller that will respond to proportional and non-proportional interfaces; 2) to technically and clinically evaluate the performance of the prototype controller and the relative user driving response; and 3) to develop a manufacturing prototype of the controller and seek a manufacturer.

Progress—A unique wheelchair controller has been developed that can interchangeably respond to both proportional and digital control interfaces. This controller incorporates a motor speed control-loop which behaves in a fashion similar to cruise controls in modern automobiles and automatically compensates for environmental factors such as sidewalk slant, varying terrain and torque demands. For the clinician's convenience, the input circuitry of the controller was designed in such a manner that it

automatically recognizes the type of interface being connected to it and selects the appropriate decoding strategy. Rapid interchanging of interfaces is therefore possible for assessment purposes or as an individual's physical condition deteriorates.

The back electromotive force (BEMF) generated by the permanent magnet motor, proportional to the angular velocity of the motor's shaft, is used in closed-loop speed control circuit. An analogue error signal, proportional to the difference between the selected speed and the BEMF signal, modulates two bi-directional pulse train outputs in proportion to its amplitude and polarity. An analogue data selector is used to direct the modulator's signals to the appropriate inputs of the MOSFET power bridge, and thereby derive the desired response from the motor.

A power MOSFET "H" bridge was developed to provide more efficient power switching to the

wheelchair motors when operated at 20 kHz. Closed loop dynamic and static braking circuitry was implemented in the design. Acceleration and deceler-

ation rates are each independently adjusted via potentiometers.

Assessment Protocol for Prescription of Powered Mobility Devices

S. Jarvis, B.Sc., P.T.; W. Lotto, M.D., F.R.C.S.(C), F.A.C.S.; J. Staub, M.A., C. Psych.; M. Young
Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: The Hospital for Sick Children Foundation, Toronto, Canada

Purpose—This project studied predictors of successful powered mobility driving, with the goal of preparing an assessment protocol for the prescription of powered mobility devices. Currently, such a protocol does not exist. It appears that each prescribing Centre has a method of prescribing powered mobility devices which is based in part on the prescriber's clinical experience, and in equal part on trial and error. The approach taken in this study was to first determine which, if any, measures predict powered mobility control, and then base an assessment on these predictors.

Progress—Fifty-seven subjects were seen in this study: twenty-four were able-bodied subjects, and thirty-three were disabled. All were subclassified into three age groups (i.e., 4-5, 6-7, and 8-9 years old).

Subjects were further classified according to physical ability level (i.e., able-bodied, walk-with-aid, walked into clinic, non-walker); according to experience with mobility devices (i.e., no experience, manual wheelchair, electric wheelchair, and passively mobile); and, according to diagnosis (cerebral palsy, diplegic and quadriplegic involvement, spastic and athetoid, spina bifida, spinal muscular atrophy, hemiparesis, and one subject each with quadrilateral amputations and head injury).

A large battery of standardized motor, perceptual, and intelligence tests was administered, including: *Motor*: Peabody Motor Development Scale; *Perceptual*: Motor Free Perceptual Test and Ayers Space Visualization Test; *Intelligence*: WISC-R or WIPPSI MAZES; Raven Colored Progressive Matrices; Peabody Picture Vocabulary Tests; WISC-R

Picture Completion Subtest; WISC-R Picture Arrangement Subtest; Representative Stencil Design Test; *Vision Examination*: carried out with 30 percent of the disabled subjects.

All tests in this battery were administered and scored in the standard way. In addition to this test battery, four computer-based pre-driving tests, two computer-simulated driving tests and two actual driving tests (wheelchair and remote-controlled driving tests) were performed by the students. Pre-driving tests consisted of a targeting test, a tracking test, a test of dynamic perception and a simple maze. All driving tests (simulated and actual) use the same five courses which were to be traversed in one of two speeds. These courses consisted of: 1) straight-away; 2) S-curve; 3) sharp (90 degree) left turn; 4) backing up and sharp left turn; and 5) two sharp right turns. For simulations and remote-controlled driving tests the courses were scaled to the size and speed of the moving object.

Preliminary Results—Data collection was completed during the summer and data coding and analysis was commenced. All data processing is being carried out using SYSTAT (version 2.1). Analysis steps to be completed are: a) comparisons of means by subject groups and age groups; b) testing of regression models for each of the test domains (motor, perceptual, spatial, verbal, pre-driving, simulation and remote); c) selection of predictors by test domain and subject (ability) group.

Publications Resulting from This Research

Assessment Protocols for Prescription of Powered Mobility Devices. Jarvis S, Lotto W, Staub J, Young M, Verburg G, *Rehabilitation Digest*, 17(2):12, 1986.

A "Smart" Controller for Electric Wheelchairs

Ian R. Loudon and Paul Nisbet

Bioengineering Centre, Princess Margaret Rose Orthopaedic Hospital, Edinburgh EH10 7ED Scotland

Sponsor: Lothian Health Board, Scottish Education Department

Purpose—The aim of this study is to produce an adaptable and programmable controller which can be used with a standard electrically-powered wheelchair so as to allow the severely disabled user a degree of independent mobility. The controller will also operate as a simple communication device which will enable the same switches to be used for both functions, thereby simplifying the learning process and providing greater incentive for the development of control skills.

Progress—We have produced two prototype controllers which are based on the Rockwell R65F12 microprocessor and which are programmed in Forth. The controller is capable of monitoring bump detectors, proximity sensors, wheel position sensors, a line follower and several user inputs. The input devices include single and double switches, switched and analogue joysticks and direct input from portable computers or communication aids.

The control software is written in Forth and is currently under development. It is based on a queued data structure and uses a modular program construction. By connecting the controller to an external computer, the appropriate operating mode can be selected to suit the individual needs of the user.

The degree of assistance which the controller

provides varies from following a preprogrammed course to a completely user-controlled mode. The speed and acceleration of the chair can be limited where appropriate and a number of experimental control systems involving feedback to the user by special joysticks are being investigated.

The safety of users with limited control abilities has been enhanced by the incorporation of bump and proximity detectors which slow the chair down as it approaches obstacles and stop it in the event of collision. Other sensors keep the chair moving in a straight line on uneven surfaces or allow it to follow a path marked on the ground.

Future Plans/Implications—Trials will begin soon with a group of wheelchair users who have no means of controlling their chairs at present. This group covers a broad spectrum of physical and mental handicaps with several multiply-handicapped subjects. A variety of control schemes based on the principles of external physiological proprioception (developed by the Bioengineering Centre while investigating the control of arm prostheses) will be adapted to wheelchair control by means of specially-produced joysticks. This work should improve the quality of control for all joystick users.

C. Seating Systems

Seat Cushions for the Paralyzed

Bok Y. Lee, M.D. and Leon Bennett, M.A.E.

Veterans Administration Medical Center, Castle Point, NY 12511 and Veterans Administration Medical Center, New York, NY 10001

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is to evaluate the role of shear in pressure sore causation, to assess cutaneous buttocks blood flow of paraplegic subjects with respect to pressure sore trauma, and

develop an instrument capable of sensing buttocks blood flow for clinical prescription purposes.

Progress—Thirty-four paraplegic subjects have been

evaluated employing standard segmental Doppler ultrasound techniques, as used in the assessment of occlusive arterial disease, and also local cutaneous blood flow in the region of the ischial tuberosities while seated, as given by harmonic analysis of photoplethysmographic pulsatile waveform. The correlation is sought between known pressure sore trauma, as determined from a subject's medical records over a prior 5-year period, and the various blood flow measurements.

Serving as a control group, 23 normal subjects have also been tested while sitting, yielding data on blood flow, pressure, and shear.

Preliminary Results—To test the hypothesis that repeated pressure sores in a given paraplegic subject may be simply the result of pure chance, a Poisson distribution has been constructed, employing the average possibility of an initial pressure sore onset, as evidenced by the subject pool (50 percent). The results suggest that chance is unlikely to explain the distribution of multiple pressure sores: approximately 5 times as many subjects develop 3 or more pressure sores over the test period as may be expected to arise through chance. It follows that there is reason to seek a physical cause for at least those subjects exhibiting multiple pressure sores.

Analysis of paraplegic ankle pressure testing (ankle/brachial) data, when plotted against the frequency of pressure sore occurrence, does suggest that there is some connection between these events. That is, a least squares regression, based on a

straight-line relationship, indicates the likelihood of multiple pressure sores to increase as ankle pressure decreases, implying a connection between multiple pressure sores and an impaired peripheral arterial circulation. However, the level of significance ($P=0.08$) is low, implying considerable scatter in the results and a lack of specificity of application.

Testing for local buttocks circulation characteristics via photoplethysmographic harmonic analysis, and also plotting against the frequency of pressure sore occurrence, yields a similar qualitative trend: the more impaired the circulation, the greater the number of pressure sores. However, with this experimental procedure, the quantitative aspects are improved; the level of significance ($P=0.008$) may be regarded as highly significant. In summary, our results strongly imply a connection between local buttocks cutaneous flow and multiple pressure sore occurrence.

Results concerning vertical shear effects upon animal pressure sore threshold experimentation indicate that those tests conducted with small pistons impart much of the test load in the form of vertical shear, rather than pressure. Computations have been prepared to illustrate the extent of the misassigned load, as a function of piston diameter.

Future Plans—Additional measurements of circulation are to be assessed for pressure sore association and all results will be incorporated into a technical manuscript.

A Comparative Evaluation of Special Seating for Severely Disabled Children

William E. Fisher, Ph.D., and Barry R. Seeger, Ph.D.

Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: Channel 10 Children's Medical Research Foundation of S.A.

Purpose—In recent years a number of special seating systems have become commercially available, and this study was undertaken in order to compare special seating systems for use in Australia.

Progress—The subjects for this study were eight children with cerebral palsy or traumatic brain damage, who were selected because they required more contoured seating than padded flat surfaces. The categories of cerebral palsy involvement and

seating options defined by Hobson and Treffler (1984) were used to define appropriate seating types.

We purchased a Pin Dot Modular System, a Canadian Posture and Seating Center Modular System, a Matrix Body Support System, a Medical Engineering Resource Unit Matrix, a Canadian Posture and Seating Center Foam-in-Place System, and we also included a Hexcelite seat and a Foam-and-Ply seat.

Results—A very satisfactory result was obtained with each seating system. They all rated very highly in terms of both comfort and appearance, and the attainment of functional goals was dependent on the initial setting of achievable goals regardless of the seating system chosen. The most dramatic differences between seating systems were in terms of cost, with the Pin Dot Modular being the most expensive, followed by the CPSC Modular, MERU Matrix, Matrix Body Support, CPSC Foam-in-Place, Hexcelite, and Foam-and-Ply being the least expensive. Other comments were that the Pin Dot Modular looks very good, the CPSC Modular is easy to clean,

the MERU Matrix and the Matrix Body Support System are easily adjusted, the Hexcelite System allows good ventilation and the Foam-and-Ply seat is highly versatile.

Publications Resulting from This Research

Towards Matching Needs with Technical Approaches in Specialized Seating. Hobson DA and Treffer E, *Proceedings of the 2nd International Conference on Rehabilitation Engineering*, Ottawa, 486-488, 1984.

A Comparative Evaluation of Special Seating for Severely Disabled Children. Fisher WE and Seeger BR, *Australian Physical and Engineering Sciences in Medicine*, Vol. 10, No. 3, September 1987.

Computer-Aided Prescription of Specialized Seats for Wheelchairs

Steven I. Reger, Ph.D.; Donald Neth, M.S.; Thomas McGovern, M.S.

Department of Musculoskeletal Research, The Cleveland Clinic, Cleveland, OH 44106

Sponsor: *The Cleveland Clinic Foundation Research Institute*

Purpose—This project will develop and evaluate the computer-aided measurement and prescription of wheelchair seating supports. The scope of the proposed project does not include computer-aided manufacture of the personal body support: the focus is on the accuracy and validity of the computer-aided measurement and prescription processes.

A new concept in clinical data collection is proposed through the use of a computer-aided prescription seat (CAP-seat). The design will allow passive measurement of posture, pressure, and body contours. For the measurements, the patient will be positioned in a subjectively established sitting posture. Interactive adjustments will be carried out under operator control using the pressure and contour information provided by the instruments. The prototype fitting seat (prescription seat) will be evaluated with children and adult disability groups selected from the clinical load of the Cleveland Clinic Foundation. Postural and support data will be transferred through a telephone modem to a central location, removed from the sites of patient evaluation and fitting, for computer-aided manufacturing of seat and supports.

Progress—Two sets of an 8-by-8 array of contour gauges have been built and mounted on the back and seat of the chair for the determination of back and buttocks contour. The software used in the rapid collection of data from the fitting seat has been developed and debugged on the IBM AT, using Pascal programming language. The software has been interfaced with the I/O hardware, including an A/D board and a parallel I/O board. The contour gauges have also been interfaced and test data have been gathered. A software routine which transforms the data points into contours has been written. These contours can be viewed on the computer screen or they can be output to the graphic plotter.

Future Plans/Implications—Actual shape adjustments will be made by an array of low-pressure pneumatic cylinders acting under operator control to deform the support surface while the subject is sitting on it. Work is currently progressing on the computer interface to the pneumatic cylinders.

Weightbearing Characteristics of Soft Tissues for Body Support Applications

Steven I. Reger, Ph.D.; George H. Belhobek, M.D.; Thomas McGovern, M.S.

Department of Musculoskeletal Research, The Cleveland Clinic, Cleveland, OH 44106

Sponsor: *The Cleveland Clinic Foundation Research Institute*

Purpose—All materials used in orthopaedics for body support carry the risk of causing soft-tissue trauma because of the load transfer at the interface. However, an objective assessment of the support materials for individual need has not been developed. The efficacy of the load transfer from the support cushion to the tissues is limited by the stiffness of the structures carrying the load. For equal loads, a difference in stiffness results in higher deformation of the lower-stiffness component, which leads to shear loads and hammocking at the soft-tissue interface.

The purpose of this work is to obtain a preliminary comparison of the vertical spring characteristics (stiffness) of the composite soft tissues (muscle, fat, skin) near bony prominences versus the vertical spring characteristics of common foam support cushions.

Progress—*In vivo* soft tissue deformations under three compressive loading conditions were obtained from magnetic resonance images of normal and

paraplegic male and female subjects lying supine on 3-inch-thick polyurethane foam cushions. The loading conditions were: 1) no compression (unsupported, free-hanging); 2) body weight; and, 3) a 10kg sandbag resting on the right iliac crest for maximum compression. Surface pressure was measured for each load and location, and the soft-tissue spring constants were determined. The stiffness of the support cushions were determined using the standard indentation load deflection test.

Results—Thicker tissues were observed in the normal subjects, leading to the conclusion that higher pressure gradients must exist in the paraplegic tissues than in the normal. Bony prominences in the paraplegic tissues “bottomed out” under body weight alone, increasing the risk of tissue trauma. The stiffness of the Durafoam cushion showed a reasonable match to the spring constant of the paraplegic trochanteric area. The performance of other (viscoelastic) foam tested did not match the mechanical properties of the soft tissue areas.

Toward Further Development of a Seating System for the Physically Handicapped

W. Lotto, M.D., F.R.C.S.(C), F.A.C.S. and M. Milner, Ph.D., P.Eng., C.C.E.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: *Easter Seal Research Institute, Toronto, Canada*

Purpose—The aim of this project is to develop a modular seating system to meet the postural support needs of children with cerebral palsy. The specific goals of the study are twofold: 1) to design and develop a cost-effective modular seating system to meet the postural support needs of children with cerebral palsy; and 2) to assess the performance of the two types of modular seating systems fabricated.

Progress—A review of seat inserts dispensed at the Centre demonstrates that a large percentage of children with cerebral palsy have common postural support requirements. It is intended that this pop-

ulation be fitted with a cost-effective modular seating system.

A tubular steel frame was designed to hold the seat and back components of the seating system. Commercially available modular seat and back cushions were purchased and secured to the frame by independent vacuum-formed ABS pans. An adjustable headrest and polyester restraint straps for the trunk and pelvis were also secured to these pans.

Two types of frames were designed: the first type, intended for mildly-involved children, is the “fixed” frame. The angle at which the entire frame is attached to the wheelchair is fixed at assembly. The

second type of frame, intended for moderately-involved children, is the "tilting" frame. While fixed to the mobility base, the entire frame is adjustable to any angle from the upright position back to a 40 degree inclination. The angle between the seat and back remains constant. Both types of frames have adjustable telescoping tubes to allow for growth of the child. Also, both frames have flush bases to

permit them to be positioned on a chair when removed from the mobility base.

Preliminary Results—Two of each type of the systems have been dispensed as part of the study. The results of clinical and technical evaluations were made available in 1987.

Comparison of Pressure Monitoring Systems

Thomas McGovern, M.S.; Sandy Magnano, R.N.; Thomas P. Stewart, Ph.D.; Steven I. Reger, Ph.D.
Department of Musculoskeletal Research, The Cleveland Clinic, Cleveland, OH 44106 and Gaymar Industries, Inc., Orchard Centre Industrial Park, Orchard Park, NY 14127

Sponsor: *The Cleveland Clinic Foundation Research Institute*

Purpose—The importance of pressure evaluation in clinical assessment of body-support systems is now clearly recognized and used in many progressive hospitals and rehabilitation institutions. However, the transducers used in pressure evaluation are inconsistent, and the measurement technology is poorly defined and varies among the institutions.

Factors affecting the results of pressure evaluation are many, but the important ones are: 1) the transducer size and material; 2) load shape and its interaction with the support material; 3) the method of endpoint detection; and, 4) the uniformity of the measurement technique.

The objective of the work was to establish agreement among the three most common pressure-evaluating systems, using a clinically acceptable protocol. These results may subsequently serve to develop correction factors for shape, size, and material variations among transducers.

Progress—Interface pressures were measured by the Scimedix, TIRR, and Gaymar pressure transducers on 10 normal volunteers by two experienced independent observers. The subjects were tested in the sitting and recumbent positions, using all three transducers on three support systems successively. In the sitting position, the pressure was measured under the coccyx, ischial tuberosities, and trochanters. In the lying positions, the trochanteric and sacral pressures were observed. All measurements were repeated three times by each observer, relocating the transducers each time. All pressure values were recorded, but only the highest of each three observations was used for the statistical analysis.

The support materials were blue "egg crate" foam (EC), high resiliency 3-inch-thick polyurethane foam (HR), and the constant-pressure "Sof-care" air inflation system (SC). The support materials were made into seat-cushion and bed-cushion size pads for the measurement of contact pressures. Recumbent pressures on the egg crate foam were measured on both single and double layers, but sitting pressures were measured only on double layers of this foam.

Results—Interface pressures were measured up to 100 mmHg to minimize hysteresis effects in the vinyl transducer bags. The lower limit of the measurements was set by the Scimedix transducer, which did not provide readings less than 20 mmHg.

Linear regression analysis was performed on data collected at the Cleveland Clinic, at Gaymar Industries, and on the combined data from both locations. At each location, pressure values collected from 10 subjects using one instrument were regressed on values measured on the same 10 subjects with a second instrument. For the combined data, the regression was repeated using all 20 subjects.

All transducers tested behaved reliably and correlated well to a significant degree. When the measured pressure distributions were examined for correlations among transducers, the standard deviations were 10-to-15 mmHg. The standard deviations among cushion types, however, were in the range of 14-to-21 mmHg. This indicates more variance among cushions using the same transducer at the same anatomic location than among transducers on the same cushion at the same anatomic location.

Wheeled Mobility and Improved Seating Systems

Warren G. Stamp, M.D. and Clifford E. Brubaker, Ph.D.

Department of Orthopedic Surgery and Rehabilitation, University of Virginia Medical Center, Charlottesville, VA 22908; and University of Virginia Rehabilitation Engineering Center, Charlottesville, VA 22903

Sponsor: *National Institute on Disability and Rehabilitation Research; Rehabilitation Engineering Center Program*

Purpose—The University of Virginia Rehabilitation Engineering Center (REC) is in the fifth year of a 5-year program for research and development on wheelchairs and seating for the disabled. A part of the work on seating has been conducted in collaboration with the University of Tennessee Rehabilitation Engineering Program at Memphis under contract.

The emphasis at the REC is to conduct technical studies on all aspects of wheelchair and seating design and function that will lead to a better understanding of the principles involved, and therefore, contribute to improved design, fabrication, and prescription of wheelchairs and seating.

Progress—The REC has conducted some 23 tasks grouped under 5 areas. The work accomplished in each of these areas during the current period is presented as follows:

Ergonomics: Propulsion efficacy was evaluated at multiple work intensities for hand-rim and lever propulsion in treadmill and dynamometer simulation, and for hand-rim, lever, and “poling” under real conditions. Further model development was carried out for optimization of wheelchair propulsion efficiency. Upper-extremity motion was evaluated with respect to variation in position over a three-dimensional array and at various work intensities.

Analysis and Design of Structural Components and Systems: Work has continued on the double-drum fatigue tester (which was adopted as the ISO standard test device) to investigate the efficacy of different attachment procedures and to determine the appropriate configuration and number of cycles for the test standard. Work has been completed on the development of equations to describe the dynamic behavior of castored mobility devices as a function of load, speed, and perturbing forces. Structural analyses have been conducted on two lightweight commercially available wheelchairs, including finite element analysis. A PC-based finite-

element analysis program for wheelchair frames has been completed and is being distributed at nominal cost.

Seating and Body Support: The anthropometric data base, which includes 80 variables relevant to specialized seating, has been expanded for cerebral palsy (CP) and spinal cord injury (SCI) populations. Work has continued to determine the effects of variation in position on spasticity in CP children. Comparisons were made for different cushions to determine compression, shear and surface tension characteristics. An evaluation was made of differences in pressure distribution at the seat interface for flat and custom-contoured cushions of different density foams. Comparisons were made for pressure distribution of commercially available cushions among populations of paraplegics (both spastic and flaccid) and quadriplegics.

Electromechanical Propulsion: A patent application has been filed for a contained-electrolyte process that could result in a significant cost reduction in the manufacture of extended-life batteries. A battery charger control algorithm has been developed and tested that predicts the optimum time to stop the charging process. Work has continued on development of fault-detection capability for powered wheelchair components.

Product Design and Development: The UVA lever drive has been redesigned as an add-on unit. It has been successfully attached to commercially available lightweight wheelchairs. The compact user-adjustable wheelchair has been redesigned to reduce weight and fold more compactly. Dynamic brakes have been designed and fitted to commercially available wheelchairs: these provide control on slopes or at high speed. They also function as parking brakes. A computer-aided manufacture (CAM) system for carving custom seat cushions is near completion. This system utilizes data obtained from measurement of client surface contours to produce the three-dimensional seating surface.

VI. Independent Living for the Disabled

A. General

Design of a New Toilet: Transfer and Access Pilot Study

Pascal M. Malassigne, M.I.D.

Veterans Administration Medical Center, Decatur, GA 30033

Sponsor: VA Rehabilitation Research and Development Service (Pilot Proposal E951-PA)

Purpose—This pilot study is aimed at collecting data on the ease of approach, access, and transfer to and from a wheelchair to a toilet. In addition, this project will study body position and reaching abilities of

various user groups. This data is necessary for the preparation of a regular proposal for the design of an accessible toilet for people capable of independent transfer.

Design of Showers and Bathing Fixtures for Disabled and Elderly Veterans

Pascal M. Malassigne, M.I.D. and James A. Bostrom, M. Arch.

Veterans Administration Medical Center, Decatur, GA 30033

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Bathing continues to be one of the most significant problems experienced by many disabled people. Most existing specialized bathing fixtures and adaptive devices for use with standard fixtures are unable to meet user needs or preferences because they are often expensive, not designed for residential use, unnecessarily complicated or difficult to maintain, or so specialized that the fixture can only be used by a disabled person and not the family.

New shower and bathing fixtures have been designed to solve many of the problems with existing fixtures. Each has been developed for use by disabled and older people in residential and institutional settings. Some of the fixtures can adapt existing bathing fixtures to make them more usable and other fixtures can be installed in new construction or in renovation work. Each of the designs has been developed to be mass-produced to limit the final cost of the fixture.

Progress—Five full-size bathing and shower fixtures have been developed from working prototypes which were evaluated during 1984-1986 (see *Rehab R&D Reports* 1986). The fixtures are:

1) Two models of a fiberglass roll-in shower, one designed as a 2-piece unit (with walls) for independent use and the other designed as a 1-piece base unit for use with an attendant.

2) A full-length cushioned bathtub insert with a soft surface that fits over a standard tub to provide a raised, contoured bathing surface.

3) A partial bathtub insert made of fiberglass that clamps to a standard bathtub to provide a contoured seat surface for showering while seated.

4) A removable cushioned seat with support frame to be installed in bathtub showers.

5) A wall-mounted fiberglass seat for stall showers with a contoured seat surface.

Results—Findings from the prototype evaluations of the roll-in showers and shower seats conducted from 1984 through 1986 showed that modifications were necessary. Most changes were made to refine the shape of the seat area to improve comfort, to increase drainage in the shower seats, or to increase the size of the fixture for the roll-in showers.

Evaluation of the cushioned bathtub shower, however, showed the need for a redesign of the fixture.

To better accommodate user needs, two new fixtures, a full-length and a smaller bathtub insert, have been developed to replace the previous design. The full-length insert is a cushioned fixture made of Ensolite (closed cell urethane foam with a vinyl skin) and reinforced from behind with fiberglass. This cushioned surface limits slippage during bathing, provides greater comfort, and reduces the potential for bruising the skin.

An evaluation protocol was developed and submitted to the VA Rehabilitation R&D Evaluation Unit requesting that an independent evaluation of the prototypes be conducted prior to commercialization. The request has been approved, and plans

are being made for 70 fixtures to be distributed to five selected test sites for evaluation. Fixtures will be installed at each site and then used by disabled and older subjects for bathing for a 3- to 6-month period. Evaluations should begin in early 1988 and end in mid-year. Evaluation of the test data should be completed in late summer 1988.

Future Plans—The investigators are developing application packages which will describe each of the fixtures, their use, and installation. These packages will be used during the field evaluations and will be available to manufacturers who are interested in marketing the fixtures.

Handbike, an Arm-Powered Bicycle

Douglas Schwandt, M.S.; Larry Leifer, Ph.D.; Peter Axelson, M.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsors: VA Rehabilitation Research and Development Service; Telephone Pioneers of America; British Columbia Program for the International Year of the Disabled Person through the University of British Columbia Athletic Department; Stanford Mechanical Engineering Design Division and Stanford Center for Design Research

Purpose—The development, evaluation and subsequent availability of an arm-powered bicycle for individuals with lower limb disability will provide many benefits including fitness, therapy, mobility, integrated recreation and sport.

Progress—Six preproduction prototypes of the handbike arm-powered bicycle are now complete and ready for evaluation under the auspices of the VA Rehabilitation R&D Evaluation Unit. The Handbike rider both powers and steers the front wheel through arm-cranks which essentially replace handlebars found on a standard bicycle. Backpedaling actuates a caliper brake. The rider sits with his or her legs to either side of a crank tower, which may be lowered on to the leg rest for easy transfer to and from a wheelchair. Side casters provide support at an adjustable bike lean angle (10, 15, or 20 degrees). The side casters may also be fastened down to

create four-wheel stability for going up ramps and indoors.

Results—With the evaluation soon to begin, results will be reported in the next issue. However, informal results of test riding have been very encouraging, and a few individuals have bought Handbikes through custom bicycle builders.

Future Plans—In addition to final documentation, the current work focuses on the writing of a product manual with information about learning to ride the Handbike, and how to take care of it.

Publications and Awards Resulting from This Research

Design Development of Arm-Powered Bicycles for the Disabled. Schwandt DF, *SAE International Congress*, SAE Paper 840023, 1984.

Para-Bike: An Arm-Powered Bicycle. Schwandt DF, *RESNA 6th Annual Conference*, 3:378-380, 1983.

Federal Design Achievement Award

The Use of Capuchin Monkeys as Aides for Quadriplegics

Mary Joan Willard, Ed.D.

Boston University School of Medicine, Boston, MA 02135

Sponsor: VA Rehabilitation Research and Development Service

Progress—During the past 3 years of this project, research and development efforts have focused on the refinement and standardization of procedures by which simian aides are produced. Over the past year, a training manual and series of training videotapes were completed, allowing for replication of training results.

With the use of these training materials and supervision from an experienced trainer, college work/study students have been successful in training a basic repertoire of tasks in approximately one and one-half times the amount of time it takes an experienced trainer to achieve the same results. Via a subsidized college work/study program, college students can be hired at about 15 percent of what it would cost to hire a full time experienced trainer. Students are limited to a 20-hour work week but they can make a two- to four-year commitment to the program.

Results—Placement evaluations indicate that problems which arise tend to be in the areas of: 1) the breakdown of equipment (primarily the monkey harness which holds a shock/tone unit in place, or the laser pointer); and, 2) the quadriplegic owner's

lack of understanding of basic behavioral processes. The most common example is when the owner inadvertently rewards the monkey for engaging in undesirable behavior. A primary source of satisfaction is the durability of the monkey's learned behavior. Several owners who have spent weeks confined to their bed or hospital room report that their monkey retains mastery of tasks with little or no review. The continuing pleasure and stimulation derived from monkey/owner and monkey/visitor interactions also have contributed to owner satisfaction.

Future Plans—During the coming year, development efforts will focus on the following: 1) refining the procedures used during a placement, including the preparation of instructional video material to train the quadriplegic, his family, and aides, in proper care and management of the monkey; and, 2) further refinement of monkey-related equipment as well as duplication of every piece of equipment likely to break down. Feedback will be obtained on the success or failure of these efforts from 6 new placements scheduled over the course of the next 12 months.

Supported Employment for Youth with Learning Disabilities

David Gilmartin and Marcia Ortiz

Supported Work Employment Project (SWEP), The Center for Independent Living, Berkeley, CA 94704

Sponsor: The Center for Independent Living, Inc.

Purpose—The Supportive Work Employment Project (SWEP) is an OSERS grant funded program whose main goal is to provide severely learning disabled and multiply-disabled youth (ages 16-22) with vocational counseling, independent living skills training, job preparation, job placement, and supported work, in order to assist them in their transition from school to work.

The main goals of the project are to: 1) provide services to 30 learning disabled youth in the areas of prevocational counseling, assessment, occupational exploration, job readiness, job skills, job

placement, supportive work and on-the-job training; 2) provide supplementary services which will enhance employability, such as independent living skills training, including attitude development, interpersonal skills, and goal-setting skills; 3) familiarize and facilitate clients' use of services at CIL and other appropriate social service agencies in the area; and, 4) provide technical assistance to employers to facilitate the successful placement and maintenance in employment of clients in jobs.

Progress—The Supported Work Employment Proj-

ect is an action program, applying group work, peer counseling, vocational counseling, and supported employment principles in work with learning disabled youth. The program is taking place primarily with students of Berkeley High School, Berkeley, CA, and Oakland Technical High School, Oakland, CA. A Job Club format is used for teaching the essentials of job readiness, applying for jobs, and interviewing. These groups meet weekly.

Counseling with participants, and with their families, is a major support service. Participants also are provided support for remembering appointments and interviews, with transportation, and with morale and attitude help for approaching interviews.

Preliminary Results—Out of 42 youth enrolled, 31 remained active in the program; 25 have been placed in employment or in higher education during the life of the grant.

Future Plans/Implications—In California, state-supported funding of supported employment exists for persons with developmental disabilities, and is being developed at present for those with mental disabilities. These two disability groups are the first to be

served in supported employment because state funds exist to provide services for them, and only a rechanneling has been or will be necessary. Supported employment services for persons with severe physical, sensory, or other types of disabilities are developing more slowly because new sources of funding must be identified and secured.

At the time this is being written, funds to continue the program have not been received. The author believes regular funding for supported employment for persons with learning disabilities (in California) is 2 years away from being achieved.

We believe we have seen greater difficulty in working with older learning-disabled youth than with the younger ones. The difficulty seems related to a compound of low self esteem, low motivation, more failure experiences, defensiveness about having a disability, and more habituated ways of appearing normal while coping with a disability. The implication is that for supported employment to have maximum benefit with youth, it must be defined and programmed in ways which allow work with in-school youth, reaching even younger children than the present program has attempted.

Promoting Rehabilitation Services and Policies: Worksite-Based Employee Assistance Programs (EAPs) as Effective Advocates

Sheila Akabas; Marian Krauskopf; Ellen Brickman

Columbia University School of Social Work, New York, NY 10025

Sponsor: *The Center for Social Policy and Practice in the Workplace*

Purpose—This 3-year project will evaluate current Employee Assistance Program (EAP) practice in relation to disability management in worksettings, identify model programs in worksettings, and design new programs that will demonstrate a range of possible interventions. Finally, in the last year, conferences will be held that will present the findings of these demonstrations to an audience that may include other interested worksettings, providers of services, insurance companies, private councils, and other groups interested in worksite-based disability programs.

Progress—A mail survey of over 1000 EAPs was accomplished in the first year with over 200 sites returning the questionnaire. An analysis of this data

will appear in a survey report which will be available by the end of September 1987. In addition, five sites in New York, Connecticut, and Massachusetts have developed demonstration programs, each one examining a different approach to disability management. A sixth site, a consulting company specializing in Workers Compensation is also developing a presentation to describe their own experience with EAPs in the management of Workers Compensation cases. In April and May, 1988, three conferences are being planned, one each in Boston, New York, and Washington. These conferences, sponsored jointly by The Workplace Center and The Institute for Rehabilitation and Disability Management of The Washington Business Group on Health, will examine practical approaches to worksite disability management

generally and emotional disability in particular, as well as new research which relates to this issue. The demonstration sites will participate in presenting their experiences.

Results—Survey: Respondents represented a wide range of worksettings and 33 states. Almost one-third had 1500 or fewer employees; one-third between 1600-4000, and 20 percent had between 4000-10000 employees. The data developed a profile of the EAPs themselves. Some of the findings specific to disability management are: 1) Although most EAPs were established within the last five years, the older the EAP, the more likely they were to identify disability management as one of their activities. Another related finding is that the older the EAP, the larger the staff size. These EAPs may have the staff capacity to handle a broad rather than a single purpose assignment. 2) Organizational structure appears to influence the degree of EA involvement in disability management: 77 percent of EAPs housed in medical or 73 percent reported to the

CEO said they were active in disability management as against 52 percent reporting to Human Resources/Personnel. 3) Over one-half the EAPs did collaborate with many departments that work with disability, including Medical Health Promotion and Disability. EAPs are in a good position to help coordinate worksite approaches to disability management. 4) Although 55 percent of EAPs said they were active in disability management, it is clear that the bulk of these focused primarily on emotional disabilities. Only 5 percent of the EAP population presents with a physical disability as the major problem.

Demonstration programs are experimenting with new outreach mechanisms to identify employees and designing supervisory training to encourage early referral and the use of the EAPs in assisting in making the referral. They are also coordinating the EAP and its case management capacity with an existing workers compensation program and describing a financial mechanism for supporting light duty work.

Research Into Design Requirements for Access by Children With Physical Disabilities

John H. Bails, B.E., and Barry R. Seeger, Ph.D.

Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: Channel 10 Children's Medical Research Foundation of S.A.

Purpose—There are currently no adequate Australian or international design rules for access by children with physical disabilities. This research is intended to lay the foundation of the development of design rules for safe and convenient access by physically disabled children.

Progress—Test equipment has been designed and built, and now occupies a testing laboratory of 100 square meters. The 30 test stations include variable

rise steps, variable tread lengths, a range of ramps and curb ramps, measurement of reach, adjustable height basin, adjustable height toilet pan, various handles, shelf heights and door opening force.

Future Plans—In the latter half of 1987 it is intended to conduct tests on at least 250 young people aged 5-18 who have a physical disability, and who use a range of walking aids and wheeled mobility aids.

Development of a Trailable Ablution Unit Able to be Handled and Used by a Wheelchair User

John H. Bails, B.E., and Barry R. Seeger, Ph.D.

Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: Channel 10 Children's Medical Research Foundation of S.A.

Purpose—All trailable or relocatable toilet-type units so far produced in Australia and overseas for use

of disabled persons have fallen short of the real needs of disabled persons who want a unit they can

handle and use themselves and that will not involve a lot of setup problems and expenditure.

The aim of this project is to produce an ablution unit that can be carried to and on sites and used by disabled persons, including a person in a wheelchair, so that such persons are able, independently, to

travel to unserved beaches, parks and remote camping areas and enjoy life away from the built environment. No unit presently exists that will allow the independence that will be provided by the proposed ablution unit.

Enhanced Understanding of the Economics of Disability

Dale Hanks; Monroe Berkowitz; Stanley E. Portny; David Dean
State Department of Rehabilitative Services, Richmond, VA 23230

Sponsor: *Commonwealth of Virginia, Department of Rehabilitative Services; National Institute on Disability and Rehabilitation Research*

Purpose—The objective of the project is to enhance the understanding of the economics of disability for the further improvement of public policies and programs related to disability. The project seeks to estimate the costs of disability; study the relationship between program effectiveness and system and client variables; study the effect of program administrative and organizational structure on service effectiveness and on the disabled population; and provide information on organizational, programmatic, and funding alternatives for public policy decisions. The target group expected to benefit from this project includes federal and state legislators, federal and state administrators of programs related to disability, and ultimately all disabled people.

Progress—Our principal task is developing an econometric model of the vocational rehabilitation program. We are studying the relationships between client characteristics, services provided, and rehabilitation outcomes. The main idea of the model is to make explicit the relationships among these significant program elements. We are building a national database through the help of 60 counselors from the California Department of Rehabilitation, the Texas Rehabilitation Commission, and the Virginia Department of Rehabilitative Services. We expect to have extensive information on 1,500 re-

habilitation clients in these three states. We have not yet completed our database, but we expect completion of data collection and analysis by the end of 1987. We are also gathering data to estimate the costs of disability in the United States in general.

We are now in the final year of a 5-year project, funded in part by the National Institute for Disability and Rehabilitation Research. Data collection continues in Virginia, Texas, and California, and some preliminary analysis has been done. A final report is scheduled for publication in May, 1988.

Results—Expected results include: 1) improved methodologies for estimating the costs of disability; 2) updated national estimates on the costs of disability; 3) conceptual models to represent the relationships among rehabilitation programs, clients, and environmental variables; and, 4) current trends in the federal and state organizational structure of disability programs.

Future Plans/Implications—This project responds to a national need for a better understanding of the economics of disability. It is designed to enable public policy-makers to make more informed decisions about the optimal allocation of funds among public programs that serve disabled people.

Workstation Development for the Mobility Impaired

A.J. Bradshaw; Thomas Single; Michael Burrow

Center for Rehabilitation Technology, College of Architecture, Georgia Institute of Technology, Atlanta, GA 30332

Sponsor: Division of Rehabilitation Services, Georgia Department of Human Resources and Center for Rehabilitation Technology, Georgia Tech

Purpose—The Center for Rehabilitation Technology (CRT) at Georgia Tech is in the fourth year of an ongoing program to develop a modular, interchangeable system of workstation components for mobility-impaired individuals. The goal of the program is to develop a system of components configured and arranged to optimize the individuals's remaining mobility, strength, and dexterity in the vocational or educational setting.

In general, as a patient's mobility decreases, the need for automated assistance to complete a given task increases and is accompanied by the high cost of automation. However, the modularity of the CRT system allows custom configurations, with common components, resulting in a prescriptive device with cost-effective production.

The CRT workstation designs respond to four degrees of mobility impairment: Level 1—Poor to fair finger and hand dexterity, with the ability to use keyboard with hands and to pick and place paper and/or files by hand. No automated modules or computer control required. Level 2—Poor finger and hand dexterity and upper body strength. Has ability to slide materials about work surface. Usually restricted to powered wheelchair. Automated modules required for positioning. Level 3—No movement of upper extremities, but with some control of neck muscles. Has ability to use mouthstick. Automated modules required for material handling with robotic manipulation. Level 4—No movement of upper extremities, including neck. Mouthstick of little use. Ventilatory support usually required. Confined to bed or powered wheelchair. Sophisticated computer system usually needed for employment. Esoteric computer access usually required.

Progress—During the past year, CRT designed and implemented the Level 3 office environment workstation for a C3 quadriplegic. The computer-controlled robotic workstation has been installed and is currently being used and evaluated.

The workstation consists of two carousels, one of which contains the user's files and another which

contains three work platforms tilted at a 60 degree angle. A book elevator containing six sliding drawers holds the user's books and notebooks.

A robot arm has also been developed to be integrated into the workstation. The purpose of the robot arm is to "fetch" files and place them on one of the three work carousels in front of the user. The arm will also pull out a specified drawer of the book elevator, giving the user access to the desired book or notebook at the proper reading and mouthstick manipulation angle.

Numerous technical and human factors issues were considered and resolved in developing the workstation. Some factors which had to be considered included the interface between the computer and user, cost of the system, safety considerations for the user, ease of installation, and ease of use. The system has been developed such that it may be tailored to an individual user. All components are modular units which can be added or removed, based on the user's preference.

Developing a suitable interface between the user and the computer-controlled workstation was a major objective of the project. Because the system had to be user friendly, it was designed to minimize the number of keystrokes required, and the software was modified to accommodate the use of a mouthstick for entering data from the computer keyboard. The importance of this is especially evident when a quadriplegic needs to use word processing software; it is not possible for him to hold down one key (the shift key, for example) and strike another key at the same time.

Safety was a major concern in the development of the workstation. No exposed moving parts or protruding objects which could endanger a quadriplegic were used. In addition, the design of the robot arm avoids situations which could potentially be harmful if the arm were to fail.

The overall configuration of the workstation makes it an attractive and useful aid for many quadriplegics. The design has been carefully thought out in an attempt to accommodate as many needs of a typical

user as possible. The main objective in the development has been to make the system helpful, attractive, and easy to use.

Preliminary Results—Evaluation observations indicate that the client's independence and productivity

have increased. As he becomes better accustomed to the electronic data handling by computer and hard copy manipulation by the robot, we predict his productivity will increase dramatically. Evaluation and refinement will continue through June of 1988.

Construction of a Home Unit for Live-In Trialing of Assistive Devices

Gary L. Wilson, B.Soc.Admin., and Barry R. Seeger, Ph.D.
Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: *Housing Trust of S.A.*

Purpose—This High Technology Unit will give disabled people the opportunity to live with various kinds of technology and the latest assistive devices, in an optimal setting. Through one or two week live-in periods, even families can try and test the equipment most appropriate to meet their individual needs.

Progress—Construction began November 19, 1987, for completion in early 1988. Building plans for the structure used standard Housing Trust plans of a

unit, modified for people with disabilities. Interior, bathroom, and kitchen details will be designed in conjunction with occupational therapists. The client group is being accurately targeted, and a coordination mechanism for the various agency users is being developed. The list of possible equipment items is being finalized with loan/sponsorship issues to be settled. Users will need a scheme to supply assistive devices and modification in their own homes after testing them at the High Technology Unit.

Documenting and Utilizing Programs that Provide Community Adjustment and Independent Living Services for Persons with Spinal Cord Injury

Margaret A. Nosek, Ph.D.
Baylor College of Medicine and The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The purpose of this project is to collect and maintain information about independent living and community adjustment programs that serve spinal cord injured people; to provide an effective means of communicating new ideas and experiences among individuals operating these programs; and to provide access to a dependable source of technical assistance related to these programs.

Progress—Nonexperimental survey methodology is being used. The data from earlier administrations of this survey were summarized in frequencies according to specified categories of interest, and some correlation studies were done to determine trends in independent living program development. Data from project surveys were used to assess the

types of services being provided for persons with spinal cord injury, and the source and amount of funds being used. The survey instrument has been revised, expanded, pilot-tested, and readministered to all identified independent living programs. Data are being analyzed using univariate and multivariate techniques and will be compared to earlier findings.

In order to facilitate use of the information that is developed, the project maintains a computerized bulletin board, a telephone communication network with all the extant independent living programs, and a mailing list of approximately 2000 additional individuals and organizations. Knowledge transfer strategies depend on the specific topic or set of information, but they usually involve extensive reviews of existing literature, interviews with inde-

pendent living program administrators, staff members, and consumers, and supplementary reviews by additional experts both in and out of the independent living field.

Preliminary Results—The 1986 administration of the survey yielded a 70 percent response rate (166 programs), with 51 percent (54 programs) providing complete data. All data have been entered into the ILRU National Database on Independent Living Programs. Extensive analysis is being conducted to examine a broad array of variables related to the delivery of independent living services to persons with spinal cord injury. Preliminary results indicate that persons with spinal cord injury are served by 80 percent of independent living programs, an increase of 1 percent from 1984. Of programs meeting the criteria for independent living centers, 95 percent report serving this population. Further investigation into the significance of the “center” model is being

conducted.

In addition to data runs and reports in response to specific inquiries, there have been many products from this study to date. Two major presentations and two poster sessions on the preliminary results have been given at four national conferences to date. The Directory of Independent Living Programs has been updated and reissued five times in the past year. The new Registry of Independent Living Programs has been completed.

Future Plans/Implications—By the end of the year, a third major publication will be completed, analyzing the longitudinal database in relation to services to persons with spinal cord injuries and discussing policy implications of the findings. The ILRU project is continuing its training, networking, and information dissemination activities in the area of independent living and maintains an ongoing effort to update its databases.

An Operational Definition of Independence

Margaret A. Nosek, Ph.D.

Baylor College of Medicine and ILRU Research and Training Center on Independent Living at TIRR, Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—This project is designed to develop an operational definition of independence that spans four uses of the term: in a behavioral sense, as a psychological trait, in connection with functional abilities, and with respect to individual social performance. The objective is to develop an assessment battery to quantify an individual's independence in each of the above specified domains.

Progress—A thorough literature search, analysis of assessment instruments related to the many components of independence, and consultation with national leaders in the independent living movement led staff to decide that the primary components of independence are feelings of control, psychological self-reliance, and behavioral self-reliance. Characteristics of social independence, as originally proposed, were determined to either be subsumed under behavioral self-reliance or more accurately regarded as correlates of independence. A concept paper was developed on these conclusions and submitted to five senior project consultants for comment.

Three assessment instruments were identified from the literature to operationalize each of these factors, forming the Personal Independence Profile (PIP). Flanagan's (1973) list of life domains was modified and developed into two sets of questions with Likert-type responses, one to measure feelings of control in each life area and the other to measure the importance of each area to one's life in general. The 48 items of Fordyce's (1953) Dependence/Independence Scale which relate to feelings were chosen to measure psychological self-reliance. The Arthritis Impact Measurement Scale (AIMS) by Meenan et al. (1980, 1982) was selected as the measure of behavioral self-reliance, in large part because it covered social as well as physical functioning. A comprehensive demographic questionnaire used in a previous study will accompany the PIP to measure other personal and social variables, such as living arrangements, educational and employment status, income, health, and use of assistive devices.

Preliminary Results—The PIP has been pilot-tested

on 10 subjects identified through the Houston Center for Independent Living. A coding and data entry system has been established and implemented, and approaches to analysis have been trial tested. The Houston Center and three other centers for independent living have agreed to assist in identifying subjects and mailing out questionnaires.

Future Plans/Implications—Full testing of the PIP and the accompanying demographic questionnaire will be conducted in July. Analysis and reporting of results as proposed will be completed by the end of the grant year. Further refinement of the PIP and in-depth validity testing through two application studies are being proposed as new efforts for the next year.

Parameters of Independent Living Programs: A Longitudinal Study

Margaret A. Nosek, Ph.D.

Baylor College of Medicine and ILRU Research and Training Center on Independent Living at TIRR,
Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—This study builds on three previous comprehensive descriptive studies of independent living programs conducted by ILRU over the past ten years. (*See* “Documenting and Utilizing Programs that Provide Community Adjustment and Independent Living Services for Persons with Spinal Cord Injury,” elsewhere in this issue.) The purpose is to maintain a database on the status of independent living programs nationally and, through analysis, identify trends in their development, the emergence of new problems and new solutions for the delivery of independent living services, and changes in the characteristics of consumers of these services.

Progress—The survey used in previous studies by ILRU has been revised and refined using input received from senior project consultants. It has been pilot-tested and further refined, and administered to each of the more than 300 programs listed in the ILRU Directory of Independent Living Programs. Data has been gathered concerning populations served, services provided, characteristics of persons

providing services, methods by which services are provided and programs administered, sources of funding, and relationships between programs and their community. These data have been coded and entered into the computer for univariate and multivariate analyses, thus establishing the ILRU National Database on Independent Living Programs.

Results—The project maintains a computerized bulletin board, a telephone communication network with all the extant independent living programs, and a mailing list of approximately 2000 additional individuals and organizations. Responses are given to individual inquiries using specific data runs and reports.

Future Plans/Implications—The ILRU Research and Training Center on Independent Living at TIRR is continuing its training, networking, and technical assistance activities using these data for the benefit of any independent living program or individual interested in independent living.

The Definition of “Peer”: Consumer Perspectives and Significance in the Delivery of Counseling Services

Margaret A. Nosek, Ph.D.

Baylor College of Medicine and ILRU Research and Training Center on Independent Living at TIRR,
Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—This project is intended to provide initial data on the perceptions of disabled persons with

respect to the definition of “peer” and the provision of counseling services by peers. The consumers’

opinions will be solicited on which characteristics of peer counselors enhance credibility and lead to the highest levels of satisfaction from peer counseling services delivered by independent living centers.

Progress—Analysis of the literature search and further probing of Berkeley Planning Associates' data from the national evaluation study, has yielded several persistent questions related to peer counseling. Most available information concerns outcomes from peer counseling services and debates over appropriate techniques for delivery of these services. A question that surfaced is how consumers perceive the services; specifically, how does the consumer rate the credibility of the counselor. A design for this study has been developed which examines the degree to which these perceptions are influenced by whether or not the counselor has a

disability, the content of the interaction (disability related or not), and reputational cues given for the counselor (high or low). The dependent variable, consumer perception of counselor credibility, will be measured by the Counselor Effectiveness Rating Scale of Barak and LaCross (1975). A demographic questionnaire will be administered to all subjects after testing.

Materials for implementation of this design include photographs of the counselors, taped descriptions of the counselors' backgrounds, and the content of the interactions. Due to limited financial resources for material preparation, it was decided to examine only the perceptions of persons with physical disabilities for this study. The pilot test, refinement of materials, initiation of full testing, and dissemination of results will occur before the end of this project year.

Independent Living in Rural Areas: A Longitudinal Study

Margaret A. Nosek, Ph.D.

Baylor College of Medicine and ILRU Research and Training Center on Independent Living at TIRR,
Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—Under a 3-year grant from NIDRR, ILRU completed a project to expand independent living opportunities for disabled residents of rural areas. Six demonstration sites were established and given ongoing support until the project was completed in April of 1986. The current Research and Training Center project is designed to examine the long-term effects of these interventions in terms of quality and quantity of ongoing activities and outcomes for the community.

Progress—The first component of this evaluation project has involved an initial assessment of three demonstration sites at the time that ILRU funding through the rural demonstration grant was discontinued. This initial assessment allowed for the collection of baseline data for comparison purposes following assessments in subsequent years. The second component is follow-up interviews of selected individuals living in the demonstration site areas. The third component will involve two follow-up examinations of these demonstration sites at 18-month and 36-month intervals.

Preliminary Results—To date, three demonstration sites have been chosen from among those previously established by ILRU. Consultants at each site have conducted the Community Needs and Resource Survey developed by ILRU during its rural demonstration project, thus establishing baseline data. Background information on these communities has also been acquired. Staff have decided to expand the original plan for interviewing residents from these communities to include groups with various levels of involvement in projects supported through the ILRU Rural Demonstration Project, i.e., advocacy group leaders, advocacy group members, community leaders, and general public. Interview protocols and a plan for data gathering and analysis are being developed. This design will be implemented at the 18-month interval from the collection of baseline data, which was July of this year.

Future Plans/Implications—By the end of this year, two sites will be visited and surveyed. Fiscal restraints have necessitated postponement of surveying the third site until the beginning of year three.

Data will be coded and entered into the computer for later analysis. The survey will be repeated at

the 36-month interval, after which comprehensive longitudinal analysis will be conducted.

Production and Satellite Broadcast of Self-help Videotapes for the Handicapped

Dr. Lois O. Schwab; Judi A. Hansen, M.A.; Janet M. Buskey, O.T.R.

University of Nebraska-Lincoln, College of Home Economics, Independent Living Rehabilitation Unit, Lincoln, NE 68583-0809

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—A new videotape series, entitled “An Orientation to Technology for the Physically Challenged,” was available as of September 1, 1987. The three videotapes are new educational tools for use by professionals to assist physically challenged individuals and their significant others in becoming aware of a general sampling of low cost devices now available to enhance a disabled person’s quality of life.

The videotape on “Communication,” featuring Dr. David Beukelman, professor of Special Education and Communication Disorders, demonstrates the use of a variety of augmented communication techniques that may be useful depending on the severity of the individual’s speech and writing disability, lifestyle, and residual capability to communicate. The “Upper Extremity” and “Lower Extremity” videotapes illustrate basic devices and techniques that help solve problems in daily living activities such as eating, dressing, cooking, and hygiene. Architectural adaptations of the environment are also demonstrated. The content sets a baseline of knowledge that all people dealing with disabilities should have. This video series will be of particular interest to rehabilitation agencies and services; independent living centers; critical care facilities; educators; physicians, nurses; patient care providers; universities and college departments: educational programs for physical therapists, occupational therapists, speech pathologists, nursing, and rehabilitation—introductory information for junior and senior students; care givers; patient and family education programs; newly disabled/physically challenged individuals and professionals not involved in rehabilitation. A brochure accompanies each tape, listing the devices in sequential numbering, the manufacturers and suppliers, company ad-

resses and phone numbers, and resources to contact for further information. The three videotapes were developed at the University of Nebraska-Lincoln through the cooperative efforts of the independent living rehabilitation unit of the department of human development and the family, college of home economics; the media services division of the department of speech education and communication disorders, teachers college; and the media department of UNL academic telecommunication, division of continuing studies.

Progress—The satellite teleconference held May 13th, 1987 was broadcast internationally to 125 sites throughout the United States and Canada. The overall objective of the teleconference was to acquaint persons who work with the physically disabled and their families with a means of providing information about the use of low cost technology in various life functions to disabled individuals and their families. Participants evaluating the teleconference and the three videotapes, provided constructive criticism for future teleconferences and suggested revisions for the tapes.

Preliminary Results—Preliminary results of the pre- and post-evaluations indicate a most favorable response: 1) interest in utilizing the tapes in a magnitude of ways “As an instructional tool with patients, as an educational program for O.T.’s, P.T.’s, nurses, and as introductory information for students.” 2) “All those who work with the handicapped should see it, along with the handicapped, themselves.” 3) Requests for additional teleconferences and video series on related topics: case studies, devices for specific disabilities. The final report was completed in October 1987.

Development of Design Criteria and Performance Standards for Barrier-Free Environments

M.A. Wylde, Ph.D.; K.S. Bunch, Ph.D.; J.R. Zellner; A. Baron-Robbins; T. Festervand, Ph.D.
Advanced Living Systems Division, Oxford, MS 38655

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The purpose of the project is to develop a comprehensive set of design criteria and performance standards for architectural designs and furnishings that will enable the severely disabled to function independently in private or public environments. To meet this primary goal, specific tasks will be accomplished for the following objectives: 1) Collect and analyze human factors data to delimit the spectrum of human abilities and to develop quantifiable descriptors of human performance relevant to the tasks of daily living activities; 2) Develop design criteria and performance standards for furnishings and architectural designs for barrier-free environments; 3) Ensure that the design criteria and performance standards are applicable to all housing and public-use building types are acceptable to the target groups of end-users (both able-bodied and disabled); builders, architects and developers; and professionals in related fields; 4) Determine the costs associated with constructing barrier-free environments built according to the design criteria and performance standards and compare to a) the costs associated with constructing conventional housing and b) the costs of providing alternative housing options for disabled individuals.

Progress—Two data collection procedures will be used to gather new information. 1) The first will measure human factors for descriptive analysis. It

will include two-dimensional measurement of human movement using a digital camera system. This human factors data together with data from a comprehensive search of the literature will be used to generate new design criteria and performance standards; and 2) The second collection of data will be an experimental study to test the new design criteria and performance standards. The data will be collected in two settings. The control environment will be constructed according to existing standards: a model apartment will be constructed according to design criteria and standards established as a product of the initial stage of this grant. Human subjects will perform designated daily living activities in both settings.

Future Plans/Implications—Based on the findings of the second data collection, experimental design criteria and standards will be revised. Applicability and acceptability for the new design criteria will be determined by a target group of end-users to include builders, architects, developers, and professionals. A culminating activity will be development of sample plans for public and residential buildings to include cost benefit analyses. Possible directions for the future are envisioned as the project progresses. At the conclusion of the project, more specific implications for future research will be indicated.

Computerized Task Guidance for Cognitively Impaired People

N.L. Kirsch, Ph.D.; S.P. Levine, Ph.D.; L.A. Jaros, B.S.
Rehabilitation Engineering Program, Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center, Ann Arbor, MI 48109

Sponsor: *Robert Wood Johnson Foundation, Princeton, NJ*

Purpose—The general aim of this project is to test the hypothesis that a computerized task guidance system can be used to improve functional performance of complex tasks for individuals with moderate to severe neurocognitive deficits. This type of intervention, which we have termed a cognition or-

thosis, has the potential to facilitate user performance for a wide range of functional activities, dramatically increase independence, and ease the responsibility for costly care typically assumed by family members or community facilities.

Progress—Over the past four years, a computerized cognition orthosis system has been developed in our laboratory, in an attempt to meet the needs of brain-injured individuals who no longer respond to restorative therapies and need compensatory intervention to perform functional tasks. This system is used to develop “Instructional Modules” (IM’s) which guide cognitively impaired individuals through functional activities. A specialized computer language called COGORTH (from COGnition ORTHosis) has been written for these applications and is described in an accompanying report. In earlier research, the efficacy of COGORTH IM’s was studied with a cognitively impaired patient. This patient was unable to complete many daily life tasks without assistance. However, using a specifically designed COGORTH IM, the subject was able to complete a complex cooking task without error.

Current studies include: 1) the use of IM’s to determine whether computerized task guidance and cueing can permit cognitively-impaired people to independently perform a vocational (janitorial) task which they could not otherwise complete on their own. This project will be expanded in the second year to include multiple concurrent tasks; and, 2) the development of IM’s for various daily living activities (washing, dressing, food preparation, etc.) for patients in both our inpatient and outpatient rehabilitation programs.

Preliminary Results—Trials with two inpatients have led to marked improvement in their performance of daily activities. There has been some apparent carry-over to performance even without computer assistance, although recovery is also playing a large role, as these interventions are being imposed at relatively early stages of rehabilitation.

Future Plans/Implications—Discussions are under way with a number of different centers to establish trials of COGORTH IM’s, with a wider range of participants (i.e., geriatric) and environments. Libraries of COGORTH IM’s are gradually accruing with each new attempted application. These libraries greatly facilitate development of new IM’s, as existing routines can be incorporated either as is, or with modifications, into new cognition orthoses. Another planned effort is to develop an intelligent mobile (i.e., robotic) base which will allow a computerized task guidance system to either follow or lead an individual through his/her environment.

Publications Resulting from This Research

The Microcomputer as an Orthotic Device for Cognitive Disorders. Levine SP, Kirsch NL, Fallon-Krueger M, Jaros LA, *Proceedings of the 2nd International Conference on Rehabilitation*, 130-131, 1984.

The Microcomputer as an Orthotic Device for Patients with Cognitive Deficits. Kirsch NL, Levine SP, Fallon-Krueger M, Jaros LA, *Journal of Head Trauma Rehabilitation*, 1987 (in press).

An Infant Crib for Use by Wheelchair-Bound Parents

Micheal D. O’Riain, Ph.D., P.Eng., and Gilbert Layeux, Reg. Tech.

The Rehabilitation Centre, Ottawa, Ontario, Canada, K1H 8M2

Sponsor: *Rehabilitation Centre: The Royal Ottawa Hospital*

Purpose—The objective of this project was to design an infant crib which could be used by a wheelchair-bound parent. The number of wheelchair-bound persons who are having children has increased the number of demands for such a crib. Conventional cribs are difficult to use by these parents, because it is difficult for them to lower the side and, once lowered, the side keeps the wheelchair at an unsafe distance.

Progress—A prototype crib has been constructed and is currently under evaluation to ensure its safety

and to determine its usefulness. The new crib is higher than conventional cribs, to allow easy access by wheelchair-bound persons. The side slides open horizontally, allowing the parent direct access to the infant. Double locks, which engage automatically on closure, prevent accidental opening of the doors.

Future Plans/Implications—Once the new crib is determined to be safe for use with infants, an evaluation will be made with the assistance of wheelchair-bound volunteers and their infants.

Multi-Adjustable Forearm Support Walker

J.R. Linskill, M.Sc., and E.R.C. Draper B.Sc., (Hons) M.B.E.S.

Bioengineering Centre, Princess Margaret Rose Orthopaedic Hospital, Edinburgh EH10 7ED, Scotland

Sponsor: Scottish Home and Health Department

Purpose—For cerebral palsied children who cannot support their own body weight through their legs, but are potentially independent ambulators, such as some spastic diplegics, it is normal in this country to employ a Zimmer-type walker with forearm supports to train their gait. The position of support, with the forearms supported horizontally ahead of the child at the high thoracic level, while being relatively stable and therefore reassuring, is far from ideal. It means that the torso is held in a forward leaning position that leads to ungainly and inefficient gait. Far more importantly, however, is the fact that it is not helping to train the coordination required in the muscles of the trunk for balance. An attempt is being made to see if better positioning is possible.

Progress—A multiply-adjustable walking frame has been designed and produced by the Bioengineering Centre. The frame itself is adjustable in three dimensions and the forearm supports are easily adjustable with six degrees of freedom. The device is currently being tested at a specialized school with physiotherapists experimenting with different walker configurations. A protocol is currently being set up for more formal tests to be carried out, that will allow qualification of the different configurations. These will include kinetic, kinematic and electromyograph (EMG) data using a VICON system, as well as Physiological Cost Indices obtained from electrocardiogram (ECG) data that will show the clinical value of such a device.

Walker for the Young Cerebral Palsied Adult

J.R. Linskill, M.Sc., and E.R.C. Draper B.Sc., (Hons) M.B.E.S.

Bioengineering Centre, Princess Margaret Rose Orthopaedic Hospital, Edinburgh EH10 7ED, Scotland

Sponsor: Scottish Home and Health Department

Purpose—Many researchers have looked into mobility for the young cerebral palsied child and there are now a number of devices currently on the market that provide different degrees of mobility. As the child develops into a young adult, however, increase in size causes a number of problems that restrict their mobility. Most of the designs available would be unstable with a much larger occupant. There are also the other practical difficulties, in that it becomes increasingly difficult to mount a larger child in such a device, and once there, the extra weight makes it very difficult to support them comfortably. It is

intended to produce a walker suitable for this purpose.

Progress—The design is currently underway for a multi-adjustable walker for young cerebral palsied adults. The device will allow the testing of different body orientations and different support regimes to determine the optimum. This will include an investigation into the practicalities of mounting/dismounting such a device. It is intended to quantify the effect of different configurations using full gait analysis and physiological cost indices.

Rehabilitation Engineering Center

Gerald E. Miller and William A. Hyman

Bioengineering Program, Texas A&M University, College Station, TX 77843

Sponsor: Texas Department of Mental Health and Mental Retardation

Purpose—This program is designed to provide on-site rehabilitation engineering consultation and serv-

ice delivery at selected state Mental Health and Mental Retardation (MHMR) facilities in the Gulf

Coast region. It brings University engineering faculty and students in contact with MHMR personnel and clients for the definition, selection, and execution of design projects which will benefit individual clients, serve as a prototyping activity for client devices needed by a group of individuals, or be used with the facility for client treatment or education.

Progress—This report reflects the first six months of the program. Preliminary efforts consisted of meetings at each facility to acquaint the respective staffs with the nature of the program and the types of projects which were consistent with time frames and available resources to produce the designs.

Preliminary Results—Projects to date include the design of a multipurpose adjustable wheelchair frame which could accommodate several devices used by the client. A headwand-operated joystick controller and speech synthesizer were also modified to make them more useful to the client. Seating problems were addressed to provide greater stability to a variety of clients so that other activities and training could be more effective. Several communication devices for non-verbal and motor-limited clients were developed which allow for very simple selection from an intentionally limited menu. A variety of input devices to the communication systems were developed ranging from simple switch activation to foot operation. A similar system for educating developmentally-delayed children was also provided which could accommodate both pictures and real objects for selection by the child at the direction of the therapist. A custom table to accommodate this system was designed and built which provides added stability for the child using the device. Additional projects included an arm-operated aerobic exercise machine, several types of interfaces between client-

operable inputs and typical environmental devices, and training devices which provide a reward feedback in the form of operation of a radio or similar appliance. Sheltered workshop task design problems were also addressed to improve worker efficiency and to bring new contracts to the workshop. Non-design activities included general consultation with, and training of, therapists in the application of commercially available rehabilitation and general consumer equipment.

Future Plans/Implications—Early experience with this program demonstrated that there is a significant need for engineering design input for a wide variety of client problems at these facilities, and that many of these needs can be expediently met by a visiting or on-call engineering team. This service delivery model has distinct advantages in that continuous on-site engineering services could not be effectively utilized by these facilities at this time. Moreover, this program brings an array of expertise and experience to each facility as well as the resources of the University for fabricating selected projects. Future plans include expanding the program to cover more state facilities and interfacing the program with newly-developed NSF funding which is aimed at the development and implementation of undergraduate student design projects. As further experience and projects are generated, technology transfer between the needs of the various facilities and short course technology training for on-site therapists will be developed. The broad implications of this effort are that coordination of activities between state agencies can efficiently enhance their programs. For the engineering student, this program provides an opportunity to solve real-world problems, obtain exposure to rehabilitation engineering, and gain a deeper understanding of individuals with handicaps and their needs.

Systems to Enable Physically Handicapped Persons to Board Inter-city Buses

Micheal D. O'Riain, Ph.D.; P.Eng.; Louis Goudreau, B.Sc.A.; Jacques Sibille, P.Eng.; Gilbert Layeux, Reg. Tech.
The Rehabilitation Centre, Ottawa, Ontario, Canada, K1H 8M2

Sponsor: *Rehabilitation Centre; Transport Canada and The Royal Ottawa Hospital*

Purpose—The purpose of this project was to design new systems that would enable physically handi-

capped persons to board standard inter-city buses. Where possible, the systems were to be sufficiently

portable so that they could be carried in the luggage compartments of buses. However, station-based systems were also to be investigated. Our designs were to encompass as wide a range of inter-city buses as possible.

Progress—The entrances and aisles of inter-city buses are steep and narrow. This represents a major problem for any boarding system to be used by handicapped persons. In designing our systems to get around these constraints, we used the following strategies: 1) The subjects were first transferred from their own wheelchairs to special narrow wheelchairs which would fit through the entrance of the bus and into the aisle as far as the first row of seats. 2) To enable level transfers to be made into the bus seats, and to increase the width of the aisle by a

few inches, we specified that the two armrests on the front row of seats be equipped to pivot upwards and out of the way.

Three systems have been designed and scale models have been constructed. The differences between the systems are the methods used to get the user in the special wheelchair from ground level to alongside the front row of seats. Two of the systems are portable and could be carried in the luggage compartment of the bus for use at the destination. The third system uses a permanent ramp and would have to be based at the bus terminal.

Future Plans/Implications—We plan to build full scale prototypes of our designs so that they can be evaluated in use.

Development of a Wheelchair-Accessible Weight Training Gym

S. Naumann, Ph.D., P.Eng.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: *Variety Village Sport Training and Fitness Centre, Toronto, Canada*

Purpose—This study had the following objectives: 1) to design and fabricate a self-contained weight training device which is versatile, accessible to and adjustable by the wheelchair athlete; and 2) to assess the performance of the device at the Variety Village Sport Training and Fitness Centre.

Progress—Wheelchair athletes experience special problems using existing weight training equipment. Awkward equipment adjustments, wheelchair inaccessibility, and lack of user independence often lead to user frustration and discouragement. The weight training device developed for this project is multi-adjustable and incorporates many of the functional features of commercial multi-station gyms. However, this device has the added advantage that safe operation is possible while the user is seated in a wheelchair.

The weight training device consists of a tubular steel frame, a push bar and an adjustable push bar guide, two selectable weight stacks, two pulley system sets and a user safety guard. The frame of the device is free standing and is constructed of 2-inch diameter heavy-walled, cold-rolled steel tubing. This structure is configured to permit the user to enter the rear of the device in a wheelchair and

remain in it while lifting weights. At the front of the frame is a weight press bar guided by Delrin bearings on two parallel centerless ground tubes. These guides preclude user injury caused by inadvertent rotation of the push bar. Two locking gas springs are attached to the guides to offset the weight of the guides and to permit the user to adjust the angle of weightlifts over an angle of 90 degrees.

Weights are applied to the push bar through a cable/pulley arrangement by two sets of weight plates located outside the basic frame. Each weight stack contains ten 4-kilogram weight plates. The number of plates lifted by the user is determined by the location of the adjustment pin in each weight stack. The pin has a 1-inch diameter ball attached to its end to ease pin relocation for users lacking fine motor control. The weight stacks are located such that the user can make adjustments without repositioning the wheelchair.

Future Plans—This weight-training device was fabricated in 1987. Assessment of the function of the device will be conducted at Variety Village with the assistance of a number of wheelchair users who will use the equipment regularly for a period of 1 month.

B. Robotics

An Instructable Robotic Aid: A Pilot Proposal

Colleen Crangle; Patrick Suppes; Stefan Michalowski; Larry Leifer

Institute for Mathematical Studies in the Social Sciences, Stanford University, Stanford, CA and Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: *VA Rehabilitation Research and Development Service (Pilot Proposal #B942-PA)*

Purpose:—This proposal discusses a vital enhancement to the existing Robotic Aid for the severely disabled. At present, user-communication with this robot is restricted to one-word commands that correspond to predefined primitive actions. Our goal is that this robot understand complete sentences as customarily used by ordinary speakers of English and learn how to perform new tasks as a result of the instruction it receives in English. The disabled user, like most of us, is a computer user not a programmer. If the Robotic Aid were to understand natural English commands and questions, the full power of the robot would be placed in the service of the disabled user.

To achieve our goal, we will apply research in the syntax and semantics of English to provide the Robotic Aid with language-understanding capabilities. Our purpose is to “close the gap” between English and the primitive machine operations of the robot. During the nine-month period of the pilot study, we will: 1) analyze the requirements of a natural-language interface to the Robotic Aid, paying

particular attention to the needs of disabled users; 2) identify a set of tasks for the robot that are appropriate to the needs of the physically disabled; 3) formulate a range of English commands for instructing the robot in these tasks and extend the existing natural-language interface for these commands; and, 4) implement a practical application of a prototype system, one that allows a disabled user to communicate with the Robotic Aid in a typical room environment.

This program of work will form the foundation for a long-term joint project that will advance both theoretical work on natural-language interfaces to instructable robots and work on the design of robotic aids for the physically disabled. At the end of this initial nine-month period we will produce: 1) a substantial proposal for long-term research; 2) specifications for an instructable robot system that takes the needs of the physically disabled user into account; and, 3) a demonstration of the preliminary language-understanding capabilities achieved.

Clinical Evaluation of the JHU/APL Robotic Arm

Robert W. Hussey, M.D. and Barry Taylor, M.S., O.T.R.

Veterans Administration Medical Center, Richmond, VA 23249

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose:—Computer-based robots can enhance the quality of life for those with high level quadriplegia and other severely motion-impaired people by improving self esteem, reducing the cost of attendant care, expanding avocational and vocational horizons, and providing greater mastery of the physical environment.

This research project was designed to determine the effectiveness of the JHU/APL robotic arm/worktable system performance and to determine the

practicality of this system for satisfying the needs of high level quadriplegic persons in attaining independence. The tasks currently being evaluated by spinal cord injured (SCI) patients using the JHU/APL arm include feeding, fetching liquids, tissues, reading materials, a mouthstick, and permitting access to a Mac Plus computer with hard disk drive and to a phone.

Progress:—The aesthetics of the robot’s movement

and hardware appear to be very significant for user acceptance of this technology. With the JHU/APL robot, a concerted effort has been made to physically approximate a human arm. Also APL has incorporated motion trajectories which often have 3 axes of the arm moving simultaneously (simulating normal human movement), in an effort to make the robot more socially and psychologically acceptable to the user and significant others. This year a 180-degree wrist has been added to the arm, which has increased functional ability and proved very reliable.

Another major consideration in achieving optimum user acceptance is the computer control interface. The APL robotic system utilizes a chin controller which provides the operator a natural extension of his intact motor and sensory abilities. This year, the chin cups have been modified so that they can be custom molded to the face of each individual user.

No knowledge of computer programming is required to operate the robotic arm—the on-board microprocessor is preprogrammed by the therapist to perform complex tasks in response to one or two commands from the user. This preprogramming approach to operation was selected in the interest of user time and energy efficiency, but the operator can assume direct manual control of the arm at any time and interested clients and/or significant others can learn to write their own programs with limited instruction. In March, the EE PROM memory was doubled to allow space for entry of complex programs. Since computers, like robots, are perceived as intimidating by a significant segment of the public, the APL robotic software has been kept very simple and extremely user friendly, minimizing operator training and high tech intimidation. In 1987, the software was modified to remain in the program mode after the completion of a task.

When writing computer programs for a particular operator, efforts are made to “custom tailor” tasks for the specific user as a way of personalizing the robot. For example, in the feeding program, provisions are made to allow for maximum operator control over food presentation, including which type

of food is presented, the speed of food presentation, etc. This approach has proved very helpful in maximizing user participation.

A training manual is currently being developed to explain components for controlling the arm, manual operation of the arm, and the function of each individual program in the R.A./WT computer. In addition, a new Air Force headset-type telephone and a large-capacity fluid container are being incorporated into the worktable unit.

Results—Since February of 1987 the robotic arm/worktable has been evaluated extensively by male persons with quadriplegia between the ages of 21 and 60. The length of time from the date of their injury ranged from 1 to 10 years. The levels of injury ranged from C1 to C5. All of the users found the experience restored their sense of independence and self worth; these operators all expressed a desire to purchase a unit of their own if one were available. The tasks rated as most beneficial were feeding, fetching fluids, and accessing the personal computer and the phone. Negative comments centered around the incompleteness of the toothbrush and hairbrush programs. No safety problems have been encountered. The wheelchair-mounted chin controller is preferred to the table-mounted controller for operation of the arm as it affords independence in coming and going from the workstation.

Future Plans/Implications—Plans for the future include the commercial manufacture of 15 robotic arm/worktables, which will undergo acceptance testing at selected VAMC/SCI centers throughout the country, and the evaluation of the first commercial arm at VAMC Richmond. Concurrently, the VA will develop training materials for therapists and veterans who will work with the arm. A joint project is just under way which will marry the computer hardware and software from the VA/Stanford University program with JHU/APL robotic arm, with evaluation of this generation prototype to be conducted at Richmond VAMC.

Application of a Robotic Aid for the Severely Physically Disabled

Larry J. Leifer, Ph.D. and Inder Perkash, M.D.

Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: *VA Rehabilitation Research and Development Service (Project #B239-2RA)*

Purpose—The long term goal of the project is to enhance quality of life for the severely physically disabled by providing increased independence in functioning through the use of robotic aids.

Specific objectives of the project are to: 1) place and evaluate the stationary robotic aid in the home or office setting for both personal and vocational applications; 2) continue upgrading a second similar prototype system in the clinical setting at the Palo Alto Veterans Administration Spinal Cord Injury Center, based on feedback from in-home, in-office

and rehabilitation application; 3) develop a flexible production prototype workstation for individualized in-home and in-office application with the stationary robotic arm; 4) define capabilities and limitations of such a system, with recommendations and instructions for use (user manual); and, 5) define specifications for an acceptable, cost effective desk top robotic aid, and meet those specifications, in order to maximize the likelihood of wide-spread utilization of robotic aids by the severely disabled.

Evaluation of a Desk-Top Robotic Aid with High-Level Quadriplegics

Larry J. Leifer, Ph.D.; Inder Perkash, M.D.; H.F. Machiel Van der Loos, EDME; Joy Hammel, O.T.R.; David Lees, M.S.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—A third-generation desk-top robotic assistant for high-level quadriplegics has been developed and clinically evaluated during the past year at the Palo Alto VA. Based on user operation of our previous prototype systems, we experienced a need to formalize the data-collection process during test subjects' use of the robot system. Comparing results from the pre- and post-test questionnaires which were used in the evaluation of the second and third generation systems gives us a valuable means of tracking our progress. Ultimately, results from these questionnaires will be used, in conjunction with quantitative performance assessments during task performance, to define future needs in enhancing the robot, user interface software, and task environment.

Progress/Methodology—The clinical evaluation staff have, for many years, used empirical data and user impressions to provide feedback to the developers, for the purpose of continuing system improvement. In addition, data collection during subject use of an earlier speech-recognition device led us to identify many significant facets of user performance related

to voice control of the robotic assistant. Our current attempt to formalize the testing process represents a next step in quantitative analysis of performance and consistent data collection of user feedback.

The robot system we are using represents an evolutionary step from last year's desk-top system. The study protocol has been stabilized, and twenty quadriplegics (levels C3-C5) have been tested with our desk-top robot. Pre-tests were given before a one-hour introductory orientation. The post-tests were given after a two-hour training session, during which the quadriplegics used the robot to perform tasks such as washing the face, shaving, brushing teeth, preparing a meal and eating it with utensils, and operating an environmental control unit to turn a radio and lamp on and off. Task assessment was evaluated by measuring completion time, subjective user satisfaction, and overall robot performance.

Preliminary Results—The pre- and post-tests administered to the twenty subjects inquire, for example, about the user's reaction to the robot's appearance, "personality," noise level, ease of learning, safety, obedience, monetary worth, and reliability. Post-

tests were uniformly more positive than pre-tests, and results on our third-generation desk-top system were uniformly more favorable than those pertaining to the older system. The task performance results confirmed the disabled user's ability to successfully complete activities of daily living using the robotic assistant.

Based on feedback from users, the robot is systematically upgraded to incorporate new tasks and to enhance the user interface. Our goal is to make the system easier to use and understand, in order to decrease user frustration and shorten the learning time needed to become proficient in using the robotic assistant.

Future Plans—In response to a need for more objective user performance measures, the current study will form the basis for a complete assessment protocol or the evaluation of future robotic assistants. The assessment will be largely automated, with the robot's controller being responsible for data gathering and will permit the development staff to track performance during typical usage. This represents a valuable and even more powerful means to quantify user acceptance of the technology, and to identify and quantify shortcomings, usage patterns, and needed future enhancements in the software and hardware of the system.

Design of a Desk-Top Environment for a Robotic Aid for the Severely Disabled

Larry J. Leifer, Ph.D.; Inder Perakash, M.D.; H.F. Machiel Van der Loos, EDME; David Lees, M.S.;
Joy Hammel, O.T.R.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The desk-top robotic aid is a state-of-the-art voice-controlled manipulation system to allow quadriplegics to pursue daily living and vocational activities. With previous prototypes, the degree of reliability and performance limitations have prevented us from attaining an acceptable level of system reliability for the robotic assistant to be evaluated outside the research laboratory. Advances in speech-recognition technology and commercial computer hardware and software have improved the user interface to the system's PUMA-260 robot manipulator significantly. The current generation of the robotic assistant can be confidently used in a clinical laboratory environment with minimal engineering support. From a system reliability standpoint, this robotic assistant can be expected to perform satisfactorily outside the clinic in a variety of locations.

The refinement of the user interface software over the past year has made the system easy to use and reliable for the tasks already programmed. Continuing studies in our clinical environment will ready the desk-top robot for formalized evaluation at other locations.

Progress—Many elements of the robotic workstation have been changed or improved over the past year

to increase overall performance. A commercial prosthetic hand, the Otto-Bock Greiffer, has replaced a simple prototype gripper. A VOTAN combined speech recognition and digitizing system has replaced an earlier generation of voice I/O hardware, and has resulted in significant improvements in speech recognition, in quality of speech feedback, and in reduction of user frustration. A new table-top environment has been designed using a fixed, easily modified tool holder in place of the large, rotating kiosk. This change has increased the robot's speed and reliability in retrieving objects. The aesthetically pleasing, wheelchair-accessible table-top robotic assistant has made the system well-suited to the clinic environment.

Software in the past year has progressed on four fronts. First, the integration of screen-based help menus and voice feedback to inform users of specific events, is complete. Second, task programming in the robot language VAL now includes at least 10 tasks spanning activities of daily living and simple clerical functions. Third, there is a complete protocol for synchronizing VAL programs with the user interface software. This is a very important step in making task programming self-explanatory to the user through the coordination of screen menus and safety warnings, and in making existing tasks easy

to modify by programmers. Fourthly, all user commands and robot actions are automatically recorded by the controller, so that subsequent data inspection and reduction by the staff can be used for future performance enhancements.

Preliminary Results—Based on testing with 20 quadriplegic users from the Palo Alto VA Spinal Cord Injury Center, the new system is perceived as being easier to use and more reliable than previous systems. Also, the number of breakdowns and malfunctions noted by clinical and engineering staff has been significantly lower with this system than with previous ones.

As an added feature, the robot system is composed entirely of off-the-shelf components, except for the task environment, which varies with the application, and several minimal modifications to the robot and controller, such as gripper wiring. The entire robot manipulator, as well as computer hardware and system software, are robust, industrial products.

The research and development of our team can

be viewed to a very large extent through the design of the user interface software: this very crucial entity represents many man-years of work and is now a very refined software package. It combines speech recognition and feedback, a well-designed graphics display to cue the user on possible commands and allowable actions, a sophisticated interface to the robot's own motion controller, and the ability to actuate an environmental controller and a modem.

Future Plans—The ongoing aim of the system design effort is to further refine the user interface software. Our immediate goal is to make it easier for the programmer to develop new tasks and add them to the robot's repertoire. Ultimately, users themselves could write and install complete tasks without extensive programming skills. This need is becoming increasingly important as the system is placed in off-site work and home settings where constant programming support is not available to users.

Development of a Mobile Robotic Aid for the Severely Disabled

Larry J. Leifer, Ph.D.; Inder Perakash, M.D.; Stefan J. Michalowski, Ph.D.; H.F. Machiel Van der Loos, EDME
Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—During the past years, a number of projects have explored the potential use of robots as assistive devices for the severely disabled. Using funds provided by the US Veterans Administration, the Robotic Aid Project has developed three prototype systems. The latest of these is a voice-controlled mobile manipulator consisting of a commercial robotic arm equipped with sensors and mounted on an omnidirectional vehicle. The purpose of the current research effort is to adapt the robot for everyday tasks that a disabled person may wish to perform in a home or institutional residency environment.

Progress—The Mobile Robotic Aid currently consists of two major components: an omnidirectional mobile manipulator and a stationary operator console. The robot is intended to perform efficiently in a relatively unstructured environment, i.e., one that does not require extensive modifications from a

typical homelike setting. The Mobile System accepts spoken commands, including commands that refer to movements of the vehicle. Because of the additional three degrees of freedom associated with mobility, a dedicated color display has been implemented to assist the user in keeping track of the instantaneous state of motion of the robot. Another screen shows the location of the robot with respect to a two-dimensional map of the surrounding area. A third screen shows a black-and-white video image from a small camera mounted on the robotic arm.

Any configuration of the arm can be labeled by the user by assigning a number. Trajectories can then be assembled from the labeled configurations using a special set of spoken commands, and the trajectories can be executed at any later time with a single command. Vehicle locations can be labeled simply by designating them on a computer display, using an ultrasonic head-position detector that moves a cursor on the display in response to forward-

backward and sideways head motion.

Because the robot has no *a priori* knowledge of the environment, four sensor subsystems have been developed to enable the mobile robot to function efficiently without imposing an unreasonable control burden on the user:

- 1) A segmented touch-sensitive bumper system surrounds the mobile robot.

- 2) A low-power laser scanner is mounted on the side of the vehicle. By detecting the presence of reflectors that are placed at known locations in the robot's environment, the scanning routine can compute an accurate position and orientation of the robot.

- 3) A set of photoelectric proximity sensors are built into the robotic hand. A variety of voice-activated routines are available to the user to detect objects near the hand and (to a limited extent) to grasp those objects automatically.

- 4) A force-sensing wrist measures forces and torques between the hand and the arm. Project personnel are in the process of developing applica-

tion routines such as pushing a button or stirring liquid in a cup.

Over the past year and a half, a preliminary natural-language interface was implemented for the mobile robot. Typical commands understood (and executed) by the robot are: "Go to the desk; Then go on over to the telephone when the bumpers are hit; Slowly move backwards to within one inch of the stairs; Go northwest for three feet then face the chair." This work did not aim for broad syntactic coverage, nor did it attempt to take into account the role played by the robot's perceptual functioning in the interpretation of commands. Rather, it concentrated on the design of a basic control architecture for a commandable robot.

Future Plans—During the next period of design and research activity, a fully-functional prototype will be delivered to the VA Medical Center for clinical evaluation. Numerous hardware and software refinements will be made to ensure safety and reliability.

Robot Arm/Work Station System for High Spinal Cord Injured Persons

W. Seamone, B.A.E., and G. Schmeisser, M.D.

The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20707

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The goal of this continuing research is to complete the basic development of a working model of the robotic arm/workstation system to permit manufacturing a limited number of units at low cost, so that they may be placed in selected VA Spinal Cord Injury Centers. In order to obtain realistic data by quadriplegic users, the latest upgraded system was delivered to the VA Medical Center at Richmond, Virginia, late in 1986.

Selected quadriplegic patients have been evaluating the system to determine its usefulness for tasks such as self-feeding, reading, using a telephone, tooth brushing, and other tasks of daily living. Such evaluation can provide information on patients who would best benefit from the system, and can help develop training procedures for those who will use the system. These tests are proceeding.

This workstation has been designed with the specific goal of allowing total task accomplishments in complete safety and with little or no attendant assistance. The system is currently operated via a

chin controller located on the workstation; future plans include the examination of the use of the voice input front-end that was developed for the VA Palo Alto Robot program.

The role of the Applied Physics Laboratory (APL) during the past year has been one of fine tuning the engineering design details, assisting VA Richmond in test procedures and table equipment layout, and helping the VA prepare specifications for a commercial unit. This report summarizes some of the equipment modification concepts explored, and current plans for manufacturing.

Progress—The original robot arm/work table was designed to be controlled via a dual-purpose chin controller mounted on the wheelchair. While this design worked well for certain patients who could utilize an E&J wheelchair compatible with the controller, the concept lacked flexibility for patients with other models of wheelchairs. A table-mounted chin controller was subsequently developed to pro-

vide an alternative to the chin-operated controller. This unit is currently undergoing evaluation at VA Richmond. To further enhance the input capability, voice input is now considered as an alternative. Preliminary investigations have been made of the possibility of adapting the voice input system developed for the VA Palo Alto Robot to the APL robot arm. A demonstration is planned to verify the feasibility of this arrangement.

One new task that was added to the workstation was a tooth brushing arrangement. For this task, a disposable toothbrush with precharged toothpaste is used. The robot arm can pick up this device, squeeze the brush to make toothpaste flow to the bristles and then brush the quadriplegic's teeth, using several preprogrammed trajectories to reach different parts of the mouth. Preliminary testing indicated this program did a reasonable job of tooth brushing.

An important task on the workstation is using a personal computer. The two input techniques primarily utilized in earlier models were a mouthstick or a chin-operated Morse code keyer. These early workstations utilized an APPLE II+ or an EPSON QX-10 computer. In the most recent evaluation at VA Richmond, a MAC Plus computer with 20 megabyte hard disk was installed on the table, with a special sip/puff transducer serving as the equivalent of a mouse for high level quadriplegic users. This system is currently being evaluated and preliminary results look very encouraging.

A preliminary examination has been made of a

ceiling-mounted track suspending the robot, to allow the robot arm to transverse to 3 or more workstations. Such a system would allow each work area to be optimally designed for a single task (i.e., self-feeding). The user could command the robot to travel to various parts of the room to the desired work area. Voice-control input is the most likely candidate for control input. One solution to the power supply problem for such a system would be to use high-energy-density rechargeable batteries located in the robot arm, and provide trickle-charging via a low AC voltage applied to the track. It is estimated that the existing robot arm could be suspended from a ceiling track with only minor modifications to its mechanism.

This year's work includes only preliminary system design layout of these alternatives. No hardware mockups are planned at this time.

Future Plans—The APL robot arm/work table was selected by the VA for transition into a manufacturing prototype. Such a model has been designed, one unit constructed and evaluated. This first system did not perform adequately and was subsequently repaired and modified at APL to bring the unit into a functional operating condition. The VA has since decided to write a new specification and release the design for bids by companies for manufacture of 15 units. It was anticipated that this RFQ would be available for industry sometime during the fall of 1987.

A Robot Feeder

Micheal D. O'Riain, Ph.D., P.Eng.; Jacques Sibille, P.Eng.; Louis Goudreau, B.Sc.A.
The Rehabilitation Centre, Ottawa, Ontario, Canada, K1H 8M2

Sponsor: Rehabilitation Centre; The Kinnear Foundation and The Royal Ottawa Hospital

Purpose—The objective of this project was to design a Robot Feeder for use by severely physically handicapped persons who could otherwise not feed themselves. The advantages of the Robot Feeder to such persons would be increased independence and self-esteem. A microprocessor controller is used with our system to simplify the control of the unit, to improve the reliability of picking up food, and to bring the food safely to the mouth.

Progress—A prototype Robot Feeder was constructed and evaluated to determine its ease of control, ability to pick up food, reliability in bringing food to the mouth, speed of operation, noise, and safety. The first prototype was found to be effective in picking up food and bringing it to the mouth. However, it was felt to be too slow and to have an unsafe amount of backlash. For these reasons, the first prototype has not been given to any of our physically handicapped clients for trial.

Future Plans/Implications—The Feeder is being re-designed to correct all of the problems encountered with the first prototype. Backlash will be reduced by replacing the chain drive with a lever drive and by reducing the number of joints. “Fail Safe”

systems will be installed to insure the safety of users in the event of a system failure. Machine vision, to assist the system in locating the food and the mouth, will be added at a later time.

The following summaries are selected and re-printed with permission here from *Interactive Robotic Aids—One Option for Independent Living: An International Perspective*, Monograph 37, published by the International Exchange of Experts and Information in Rehabilitation, World Rehabilitation Fund, Inc. All of the reports from U.S. contributors were first submitted to RESNA (Association for the

Advancement of Rehabilitation Technology) and were presented at a Symposium on Interactive Robotics during the RESNA 1986 Annual Conference in Minneapolis, Minnesota. Full text of these selections and others contained in the monograph are available by writing to the World Rehabilitation Fund, Inc., 400 East 34th Street, New York, NY 10016.

Spartacus and Manus: Telethesis Developments in France and in the Netherlands

H.H. Kwee, Ph.D.

Institute for Rehabilitation Research, 6432 CC Hoensbroek, The Netherlands

Sponsor: *Institute for Rehabilitation Research*

Progress/Results—The Spartacus project was a five-year robotics project, intended to stimulate industrial robotics in France, in which a “unifying theme” was selected to be a feasibility study aimed at the development of a telemanipulator controllable by persons with high-level spinal cord lesions. A telemanipulator system was realized in two phases: first as a simulation with a commercial arm used in nuclear research controlled by a mini-computer and then by a specially developed manipulator, derived from the first one, with micro-computer control. From very early in the project, much attention was paid to control ergonomics, with the participation of a number of disabled volunteers in laboratory experiments. After the formal termination of the project, studies with various disabled persons have continued in a hospital environment.

The Dutch “Manus” Project is aimed at the development of a manipulator as a product which may be provided to disabled persons as an assistive device at an acceptable price (through some form of social security benefit). Following a one-year feasibility study, the Project officially started in 1984 with Dutch government funding for a two to three year period as a collaborative effort between four R&D institutes:

Institute for Rehabilitation Research (Hoensbroek), principal contractor in charge of over-all project management problem definition and product specification, human factors, contacts with potential users and (para-)medical personnel, cost/benefit analysis, etc.;

Institute for Applied Physics-TNO (Delft), in charge of system design, electronics and software development;

TNO Product Centre (Delft), in charge of electro-mechanical hardware development, cosmetic design, and industrialization of the system;

Netherlands Institute of Preventive Health Care TNO (Leiden), participating in a socio-economic cost/benefit analysis.

The product development is being realized by the first three institutes in very close interaction. This is necessary in order to optimize the over-all system; integrating mechanical, electro-mechanical and computer hardware, compromising between hardware and software solutions, and compromising between feasibility and costs of technological solutions on the one hand and user specifications (including functionality, cosmetics, safety and human factors) on the other hand.

The first phase of the project, now under way,

will serve to realize a first model to verify the different hardware and serve to control concepts adopted and the acceptability of the compromises agreed upon. Further development towards a prod-

uct will depend upon the outcome of the (technical) evaluation of this model, which will verify the feasibility of the objectives of the MANUS Project.

A Potential Application in Early Education and a Possible Role for a Vision System in a Workstation Based Robotic Aid for Physically Disabled Persons

W.S. Harwin; A. Ginige; R.D. Jackson

Department of Engineering, Cambridge University, Cambridge, United Kingdom

Sponsor: Milly Aphorp Charitable Trust

Purpose—At the Cambridge University Engineering Department we are investigating the use of robots to assist in the developmental education of handicapped children. The robot used in this project is the RTX manufactured by Universal Machine Intelligence LTD, London. The robot is based on a SCARA format and is, to our knowledge, the only robot with design considerations given to applications for disabled in addition to those of light industry. It has a full 6 degrees of freedom, a 1000 mm range and a load capacity of about 2 kg. A vision system is added to the robot as are gripper sensors and we hope for an eventual cost of about £10000. Although this cost is comparatively high, it is justified to keep flexibility and safety in a wide range of potential applications. The intention is to keep a flexible range of user input systems and use sensors and vision to minimize the information that must come from the user. This project is in developmental stages so success cannot be measured by commercial sales; however, other indicators are possible.

Progress—One substantial clinical trial has been made so far in which three learning tasks were investigated. Two of the tasks were suggested as basic developmental tasks that are not achievable

by children with severe physical disability, yet are central to their education. These were a routine to stack bricks in a pile and break the pile once built, and a routine to sort bricks into boxes depending on their shape or color.

The third task was the Tower of Hanoi puzzle that consists of a tower of discs with decreasing diameters which must be moved to a second location with the rules that only one intermediate location can be used and at no time can any disc be placed on a smaller disc. The robot enforced these rules but gave the user control over moving discs.

Preliminary Results—Everyone enjoyed working with the robot and it would appear to have a potential impact on someone who would not normally have done such tasks. The robot provided experiences about sounds and dimension in life. We believe this shows a potential for robots in education and would like to suggest a similar configuration for other applications. Future work hopes to expand the vision to increase field of view and possibly use it to identify unmarked objects to the robot. A more sophisticated robot control language is envisaged that would take advantage of sensor information and information in a database.

Manipulative Appliance Development in Canada: Neil Squire Foundation Project

William Cameron

Neil Squire Foundation, Vancouver, Canada

Sponsor: Neil Squire Foundation

Purpose—The Foundation robot project started in 1982 with a thorough study of the history of medical

robotics, followed by six months of data collection, mostly through interviews, with many severely dis-

abled, rehabilitation professionals, workers compensation and insurance claim groups and extended care workers.

The specifications for the first model are: 1) mass produced sales price of arm and stand-alone control electronics under \$5,000; 2) both master/slave and programmed operating modes; 3) programming to be done on any home computer. An Apple II was selected for the first prototype, and an IBM PC is being prepared for the second; 4) complexity of service and maintenance to be kept simple enough to allow for local consumer audio or computer agency servicing; 5) operation to be extremely user friendly, with no operator training being required. Specifically, no knowledge of computer programming will be necessary, and no computer keyboard will be used; 6) the coordinate envelope is approximately human-sized; 7) the appliance must be portable, with total weight to be less than 20 kg; 8) lifting capacity at worst geometry of 1.4 kg, and at most geometries of 2.3 kg; 9) use in industry in light manufacturing to be underscored.

Progress—The robot (M.O.M., a Machine for Obedient Manipulation) is designed as a work station manipulator in which the disabled user travels to the workstation (by wheelchair) and the arm operates as an attendant. M.O.M. is mounted at about eye level (to one sitting down) and can, by program, perform manipulations for tasks such as: 1) picking up a manual from a bookshelf and placing it in front of the individual; 2) turning pages; 3) picking up, serving and replacing a drink; 4) serving up a mouthstick; 5) loading a diskette in the computer; 6) picking up an electric razor and shaving a person; 7) brushing hair; 8) brushing teeth.

The TRIUMF/NEIL SQUIRE robot development to date has leaned toward fully programmed tasks with standard environmental control interfaces. It is our goal to find a suitable combination of disabled user control and programmed control that will provide performance that is user-acceptable.

An Independent Vocational Workstation for a Quadriplegic

Caroline Fu

Artificial Intelligence Center, Boeing Computer Services, Seattle, WA 98124

Sponsor: *Boeing Computer Services*

Purpose—Phase 1 of this project, which began in early 1984, initially focused on providing a speech-controlled workstation that could be used by programmers and analysts and on voice control over data later in October. We believe that if a workstation can be built for a programmer, others might be able to adapt it to satisfy the specific needs for other professions such as financial analysis, engineering, and manufacturing.

Phase II of this project, started to consider that a quadriplegic individual, when using the workstation, might impose a burden to co-workers in the environment in which the unit was to be placed. The physically-limited person could not handle such routine functions as referring manuals, retrieving printed output, loading a diskette into a disk drive without assistance, etc. The voice-controlled robotic

aids were then added to the workstation.

Results—The workstation that is in use now has a microcomputer system that supports and is driven by two voice recognition products and a voice communication product. The microcomputer is an IBM PC XT. This unit is capable of emulating different terminals which give access to multiple vendors' mainframe products. Besides, there is also a greater freedom of selection amongst voice products for the IBM PC. The voice communications product comes from Dialogic, and the voice recognition products from Keytronic and Microphonics. By April, 1986 the workstation and its operator were fully functional in a business programming environment. The operator was completely independent of supportive aid from co-workers.

Small Robot Arm in the Workplace to Aid in the Employment of Severely Physically Disabled Persons

Leonard L. Anderson, M.S.E.M.

Cerebral Palsy Research Foundation of Kansas, Inc., Rehabilitation Engineering Center, Wichita, KS 67208

Sponsor: National Institute on Disability and Rehabilitation Research and Wichita Rehabilitation Engineering Center

Progress—The Rehabilitation Engineering Center in Wichita, Kansas, has, as its emphasis, research in the area of finding means to place severely physically disabled persons in the workplace through the use of technology. A project to investigate the use of small robotic arms to assist the disabled at work has been underway for three years at the time of this writing. Several types of devices were investigated and evaluated prior to purchase. Two such types representing two distinct operating and programming criteria were purchased and have been in use on the job.

The purpose of the project was to choose a workstation which would be suitable for robotic application in the area of manipulation of workpieces, but, would also require the support of a worker in the area of quality control inspection and indexing of workpieces for the start of each operating cycle. The worker should also be able to stop the

operating cycle should problems arise. It was anticipated that a severely physically disabled person could then work at this station utilizing the robotic arm to perform the precise manipulations of small parts while, at the same time, exercising quality control (inspection) and the indexing of parts for the operating cycles.

The research project goals were to investigate devices that provided for the most articulation so that fine motor tasks could be investigated. The workstations that were chosen require the capability of the fully articulated "arm." Therefore, a more thorough investigation of robotic arm capabilities was possible.

The author and other researchers on this project have concluded that the concept of employing severely physically disabled persons by the use of small robotic arms has been shown to be viable.

CALVIN: A Robot Control Language for Rehabilitation Robotics

Scott L. Minneman and Thanh Pham

Rehabilitation Engineering Center, Tufts University/New England Medical Center Hospitals, Boston, MA

Sponsor: Rehabilitation Services Administration, U.S. Department of Education

Progress—A new control language has been developed for use with small, microcomputer-controlled robotic manipulators. The language was specifically designed for use in rehabilitation settings. Particular attention has been paid to the user interface, programming environment, portability of programs, and extensibility. The language has been introduced and well accepted for use at two clinical sites investigating occupational applications of small robotic manipulators. Application program development time has been drastically reduced and the language has

permitted the robots to be used with clients for whom a suitable interface could not previously be found.

CALVIN is a fully functional robot control language that offers its users numerous benefits over the languages traditionally supplied with the purchase of a microcomputer-controlled manipulator. Clinical trials are demonstrating that the language is robust, easy-to-learn, and extremely useful for developing rehabilitation robotics applications.

C. Communication Methods and Systems

A Systematic Analysis of Communicative Interaction Between a Nonspeaking Physically Disabled Child and a Speaking Peer: Pilot Study

P. Parnes, B.Sc., D.S.P.A.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: *Augmentative Communication Services, Hugh MacMillan Medical Centre*

Purpose—The objective of the pilot study was to investigate the quality of communicative interaction between one nonspeaking physically disabled child and a speaking peer without the presence of an adult mediator. Specifically, the study described the turn-taking abilities, topic initiation and maintenance, communicative functions and communicative modes of both children.

Progress—Two children were selected from the intensive therapy unit at the HMC School using the following criteria: 1) a nonspeaking, congenitally physically disabled child who directly accesses his/her augmentative system and has had access to this system for at least four to six months; and 2) a speaking, physically disabled peer who is of similar age and cognitive level to the nonspeaking child and who does not have any major language, vision or hearing deficits.

The interaction between the two children was videotaped for ten to fifteen minutes on three separate occasions over a period of ten school days in a free-play situation in a simulated playroom at the Augmentative Communication Service. The children were asked to play together for a short period while the investigator was "busy." The videotaped interactions were transcribed in their entirety following procedures used by Tannock (1983) and Light (1985) in previous studies of interactions between young children and their primary caregivers. The written transcripts were coded to examine turn-taking, topic negotiation and the communicative functions and modes used by the children.

Results—The data from the three videotaped samples of interaction were similar, indicating a relatively stable pattern of interaction. Results suggested that although the interaction was highly transactional with the two children influencing each other, it was highly asymmetrical. Exchanges were initiated and maintained primarily by the speaking child who contributed approximately twice as many turns and three times as many initiations as the nonspeaking child. The latter child was highly responsive, but often produced minimal responses such as eye gaze to the partner even though he had the ability to vocalize and gesture with head and hands. Most of his communicative turns consisted of confirmations, denials and protests, conveyed by means of vocalizations, gestures, and facial expressions; these nonpropositional messages were conveyed effectively and efficiently with these modes. On no occasion was the nonspeaking child observed to use his communication board with his peer, although the speaking peer was reportedly able to read many of the larger print words above the Blissymbols. It is of note that when the investigator interacted with the children before and after the observation sessions, the nonspeaking child frequently expressed his messages via his board in conjunction with other modes.

Future Plans/Implications—The results suggest that peer interactions of nonspeaking physically disabled children may be problematic, requiring intervention. These results require replication with a larger group of nonspeaking physically disabled children to establish their external validity.

Assessment of the Effectiveness of a Small, High Quality Speech Synthesizer in Augmenting the Communication of Non-Speaking Individuals

Rob E. Garrett, B.Tech.; Cathy F. Olsson, B.App.Sci. (Speech Path.); Barry R. Seeger, Ph.D.

Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: *Channel 10 Children's Medical Research Foundation of S.A.*

Purpose—Significant resources are now available to non-speaking individuals who can afford to purchase communication devices priced in the range \$A3,000-\$A7,000 and who have the physical and cognitive ability to access these devices. These comprehensive devices enable a user to type a message using a keyboard; or select words and sentences using symbols or codes and to have them spoken. The significance of these devices in augmenting the communication of non-speaking individuals is now well established.

Even though these devices have been available for a number of years, there are still a significant number of non-speaking individuals who are unable to use them because of cost or accessing problems.

There is a perceived need for a small and relatively inexpensive speech synthesizer that is portable and can be easily attached to a wheelchair or near a user. This simple device would have 1 to 8 switches which would enable immediate access to a spoken message.

The aims of this project are: 1) to assess the effectiveness of the provision of a device with a limited number of phrases, on the communication interaction of non-speaking individuals whose physical or cognitive accessing skills do not allow them to operate other speech synthesis devices; and 2) to demonstrate that the development of a simple low-priced speech synthesizer would be of value in increasing communication interaction.

Matching of Computers and Interfaces to the Needs of Tetraplegic Patients

D.S. Workman and C.G. Geggie

Spinal Unit, Edenhall Hospital, Musselburgh, East Lothian EH21 7TZ, Scotland

Sponsor: *Committee for Research for Equipment for the Disabled, Scottish Home and Health Department*

Purpose—The project aims were: a) To establish the needs of tetraplegic patients, particularly those with spinal injuries, to use microcomputers; b) to apply and evaluate alternative input devices emulating the keyboard of a BBC model B microcomputer; and c) to produce guidelines relating to safety and interconnection standards.

Progress—Five alternative input systems were evaluated. These systems represented the three methods of keyboard character selection: scanning, coding, and direct selection. The first year was spent formally assessing the use of the five alternative input systems with tetraplegic patients. The subjects learned how to use the device, then underwent a typing test. Each subject was then given a choice of equipment for long-term evaluation.

During the second year, methods of increasing speed of communication were explored. Intercon-

nection and safety standards were investigated. Work was done to increase interconnection compatibility in order to encourage a modular approach to the design of alternative input systems.

Preliminary Results—a) Currently available alternative input devices are not meeting the needs of most spinal cord injured people with a high level injury. b) Independent access and control of such equipment is important for this population, as well as a system allowing faster input speed. c) Currently available equipment is beyond the financial resources of many spinal cord injured people. Financial assistance is required to enable computer skills to develop. Initially, this could be with the alternative input device itself. d) There is a need for standardization of interconnections. e) Predictive systems appear to be of most use to people with a very slow operating speed. f) To ensure full use of

the equipment, skilled assessment and follow-up are essential.

Future Plans/Implications—It is planned to develop a system incorporating a variety of alternative input

systems configured to allow rapid interchanging of system modules. This system will allow therapist and client to experiment with different module configurations unhindered by interconnection incompatibilities.

Evaluating the Effectiveness of Direct Client Intervention and Facilitator Training for Communication Intervention with Nonspeaking Physically Disabled Children

P. Parnes, B.Sc., D.S.P.A.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: *Easter Seal Research Institute, Toronto, Canada*

Purpose—The goal of this project was to evaluate, through successive implementation, the effectiveness of a two-phase intervention program on the communicative interaction of nonspeaking physically disabled and multi-handicapped children and their parents, and to provide follow-up data two months post-intervention.

Progress—Six subjects were selected to participate in the study from the list of clients newly referred to the Augmentative Communication Service (ACS) and on the waiting list for services. Criteria for subject selection was as follows: a) congenitally physically disabled; b) nonspeaking; c) ages between three and ten years; and d) vision and hearing deemed adequate for the development of an augmentative communication system. The research project explored the cumulative effects of successive implementation of two phases of intervention procedures on communicative interaction between the children and their parents. The children and their parents were videotaped on four separate occasions: 1) baseline; 2) following direct intervention with the child; 3) following facilitator training on a group and individual basis; and 4) two months post-intervention. The videotaped interactions were transcribed and coded according to procedures developed by Light (1985). The coding data for each of the three variables (i.e., discourse status, communicative

function and mode of communication) were analyzed to determine the effect of intervention on the children and their facilitators, as well as the long-term effect two months post-intervention.

Results—Five of the six dyads showed increased reciprocity in their turn-taking patterns from initial observations upon referral to the follow-up session two months after intervention. The children in each of these dyads contributed to a greater proportion of the total turns in the interactions after intervention than they did before intervention. In fact, three of the dyads approached a perfectly symmetrical balance in their turn-taking patterns by Session 4.

The children's rates of turn-taking in four of the dyads: these increases ranged from 2.8 to 9.3 additional turns per minute. The parent's rates of turn-taking remained fairly consistent. However, the rates of responses for four of the parents increased from Session 1 to Session 4. In fact, there seemed to be a clear relationship between the child's rate of turn-taking and the parent's rate of responses.

Future Plans/Implications—The development of reciprocal turn-taking skills provides a foundation for the children's later development of more complex interactive and linguistic skills. Further research is required to evaluate the relative impact of various approaches to child intervention and parent training.

Towards Universality of Access to Information: Systems Software to Aid Access to Microcomputers by Physically and Multiply Disabled Students

B. Borthwick, Ph.D.; J. Bowles, B.A.; M. Milner, Ph.D., P.Eng., C.C.E.; P. Parnes, B.Sc., D.S.P.A.; S. Jarvis, B.Sc., P.T.; S. Naumann, Ph.D., P.Eng.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: Ontario Ministry of Education, Canada

Purpose—The Icon computer is one of two microcomputer systems that meets the functional requirements of the Ontario Ministry of Education for Grant Eligible Microcomputer Systems (GEMS). These requirements were drawn up by the Ministry to stimulate the development of network-based microcomputers designed explicitly for use in educational environments (schools, colleges). The purpose of this project is to create and evaluate an interface board that will enable physically disabled students, who cannot use the Icon keyboard and/or trackball, to access the Icon via alternative keyboards, switches, and an alternative cursor control device.

Progress—The specific goals of this project are to evaluate the Icon as is: to design and build a prototype interface that will allow for transparent connection of definable keyboards, MOD and alternative keyboards, single and multiple switches, and an alternative cursor control device; and to evaluate the interface and the operation of the adaptive devices.

The project is divided into four stages: 1) Preliminary Design; 2) Design; 3) Implementation and Development; and, 4) Field Testing.

Results—The HMMC Interface Unit (IU) is a microprocessor-based system which, when interfaced with the Icon through the external keyboard port and serial port, emulates the keyboard and trackball functions. The IU translates inputs from alternative keyboards into Icon compatible keycodes or key-code strings. Default keyboard translation tables are stored on the Icon's hard disk (Lexicon) and are downloaded to the Icon. Teachers can create individualized keyboard layouts which are stored as configuration files for specific students. A configuration file can consist of one to one (letter to letter) mapping or one to many mappings. In a one to many mapping, a key pressed on the alternate keyboard transmits a preprogrammed message or command to the Icon. This method of transmission permits

transparent access to the Icon which means that physically disabled students can use the software on the Icon system.

The current IU is hard-wired to the Icon and alternate input devices are plugged into the IU. Development of an infra-red linked remote IU is continuing. In this remote version, a transceiver unit connected to the Icon will communicate with an input unit mounted on a person's wheelchair.

The software that controls the creation and downloading of keyboard layouts and key (re)definitions has been completed and was tested during the current stage (2) of the project. In addition to this software, the user interface, instructions and support functions were designed during this stage.

The Interface Unit was evaluated with a number of commonly used alternative keyboards. Alternative devices evaluated were: a) *keyguard*: a plexi-glass keyboard overlay with holes over the keys to assist in targeting individual keys and designed for the Icon keyboard; b) *extended trackball*: a trackball mounted in a separate chassis and connected to the Icon via a 2 m extension cord; c) *extended keyboards*: Serial ASCII and parallel keyboards, e.g., RCA or Apple II keyboards connected via a cable to the IU; d) *enlarged keyboards*: e.g., Unicorn and King Keyboards; e) *miniaturized keyboard*: e.g., Mini Keyboard; f) *five switches*: mechanical or capacitive switches or a four-position joystick with selector switch; and, g) *MOD keyboard*: a front-end computer system based on a VIC 20 computer developed by NRC's Biomedical Engineering Program.

A prototype version of the IU was evaluated by the clinical team. Forty-nine physically disabled students were evaluated at the Hugh MacMillan Medical Centre School. All students required some form of adaptive interface to be able to use the Icon. The results indicate that the different levels of adaptation (extended devices to alternative or emulated devices) achieved are very satisfactory.

Future Plans/Implications—The next development phase of the IU consists of the field test in which the unit and the Teacher Utility software will be evaluated in four schools in Ontario. This field evaluation will test the principles embodied in the support software and thus the feasibility of providing on-line suggestions for interfacing students to professionals (teachers and therapists) who have varying degrees of exposure to physically disabled students and/or computers.

The Development and Clinical Evaluation of a Radio Frequency Linked, Computer-Based, Voice-Controlled Workstation for the High Level Quadriplegic

S. Naumann, Ph.D., P.Eng. and J. Bugaresti, M.D., F.R.C.P.(C)
Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: *The Ministry of Community and Social Services (COMSOC), Applied Program Technology Unit (APT), Government of Ontario, Canada*

Purpose—This study had the following objectives: 1) to evaluate three commercially available voice recognition cards for IBM PC-XT compatible computers; 2) to test voice recognition input to the computer via a radio frequency link; 3) to integrate environmental control features such as telephone management, light and appliance control, and infrared transmission into the voice-controlled workstation; and, 4) to evaluate, with C4, C5 and C6 quadriplegic subjects, the effectiveness of voice recognition as an input method to a computer-based workstation.

Progress—Three commercially available voice recognition systems were purchased for IBM compatible computers and a comparative evaluation was performed on the following systems: 1) Voice Link by Voice Works (now Voice Key by Roar Technology); 2) Voice Card VPC 2000 by Votan (Votek in Canada); and 3) TI-Speech Evaluation and Development System by Texas Instruments.

A series of vocabularies was developed which were representative of the number of commands required to access the majority of workstation functions. These commands, with keystroke outputs, were established for telephone management functions, X-10 Powerhouse lamp and appliance controller, GE Control Central programmable infrared controller, DOS commands, Wordstar wordprocessing commands and general alpha-numeric transparent keyboard operation. Each voice recognition

Publications Resulting from This Research

Development of a Microcomputer-Based Keyboard Emulator for Improved Accessibility. D'Alessandro J, Gosine R, Litrowich W, Verburg G, Naumann S, *Proceedings of the Ninth Annual Conference on Rehabilitation Technology (RESNA)*, 6:262-264, Minneapolis, MN, June 1986.

Towards Improved Accessibility of the Icon Educational Microcomputer. Verburg G, Sim J, Field D, Balfour L, Bowles J, *Proceedings of the Ninth Annual Conference on Rehabilitation Technology (RESNA)*, 6:439-441, Minneapolis, MN, June 1986.

board was tested with a vocabulary containing the standard phonetic alphabet, numeric control, basic punctuation and function key control. Once the trained vocabulary had been tested for appropriate recognition accuracy levels and any problem phrases retained to optimize recognition, all phrases in the vocabulary were tested three times. The first and second choice scores indicated by the recognition board were recorded for each utterance.

Each board was also tested to determine if training and creation of vocabularies could be completely done by using only voice commands, once a basic vocabulary had been established. The ability to change vocabularies for different applications by uploading templates from disk is an important feature for a major user of voice recognition. The limitations of each board in performing these functions and computer motherboard memory consumption were noted.

Additional board functions, such as digitized and synthesized speech output, telephone management, and the ability to output multiple key control sequences were noted and used in the final determination of the particular board to be used in the workstation development.

Two methods of radio transmission were utilized to transmit voice commands from the user to a receiver interconnected with the voice recognition board. Voice-activated FM transceivers complete with headsets were tested, along with a cordless telephone set for voice transmission. Recognition

accuracy was tested and documented, using the standard vocabulary and with both transmission techniques, in front of the computer and at a fixed distance from the computer.

Hardware was developed to adapt the General Electric Control Central programmable infrared controller for voice control via the computer workstation. Voice control of lamp and appliance control modules was accomplished through a commercially available X-10 Powerhouse controller.

A survey of quadriplegics was performed to determine the features that would be important in a workstation as an aid for daily living and as a

vocational tool. The results of the survey were documented.

The clinical evaluation of the system involves basic computer skills training, familiarization with voice control techniques, and the training of a skeleton set of vocabularies for workstation control. The trained vocabularies are to be tested for recognition accuracy with each subject and the performance noted. A script of tasks has been developed that each subject will follow and their performance at each task will be timed and any errors noted. Subjective user comments about the computer workstation will be solicited.

Toward Development of a Protocol for Assessing the Communicative Interaction Skills of Nonspeaking Severely Handicapped Individuals

P. Parnes, B.Sc., D.S.P.A.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: Ministry of Community and Social Services through the Developmental Services for Adults (DSA) Program of the Metropolitan Toronto Association for the Mentally Retarded

Purpose—The goal of the research project was to develop a protocol to assist trained clinicians in assessing the communicative interaction skills of non-speaking severely handicapped adults and their facilitators.

Progress—Essentially, the conceptual model of the assessment protocol involves six interrelated components: 1) Gathering background information in order to identify general questions or concerns which need to be explored in the assessment; 2) Observing and describing client interaction skills in client-facilitator interaction within naturally occurring contexts, in order to determine the communicative functions and modes of communication typically used by the client; 3) Investigating the client's skills further, in order to determine his/her potential to use additional functions or modes, which were not

observed in the naturally occurring contexts; 4) Setting appropriate goals for client intervention; 5) Observing and evaluating facilitator interaction strategies in client-facilitator interaction within naturally occurring contexts in order to determine the appropriateness of the support provided for the client; and 6) Setting goals of facilitator training.

The specific steps and procedures involved in each component are described in detail, and a case study is presented to illustrate the specific application of the assessment protocol.

Publications Resulting from This Research

A Protocol for the Assessment of the Communicative Interaction Skills of Nonspeaking Severely Handicapped Adults and Their Facilitators. Light J, McNaughton D, Parnes P, 1986. Available from the Blissymbolics Communication Institute, 350 Rumsey Road, Toronto, Ontario M4G 1R8, Canada.

Toward Development of a Universal Modular Wheelchair Tray for Communication, Mobility and Activities of Daily Living (ADL)

P. Parnes, B.Sc., D.S.P.A.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: *National Health Research and Development Programme (Health and Welfare Canada), and The Hospital for Sick Children Foundation, Toronto*

Purpose—The objective of this study was to develop a prototype universal modular wheelchair tray which meets the therapeutic goals of the therapist and the personal needs of the user/caregiver.

Specifically, the goals of the research were: 1) to design a prototype modular wheelchair tray which can be partially tilted to various positions and be folded away beside the wheelchair by the caregiver; and, 2) to fabricate and assess the performance of the prototype modular tray.

Progress—A prototype tray was developed to address the multiplicity of features required by a tray that is used for work, play, augmentative communication, and for daily living activities. The modular tray incorporates an independent aluminum frame, shaped plastic tray modules, tilting and locking mechanisms, and a fold-away device.

The tray frame consists of U-shaped aluminum tubing joined to two inter-connected aluminum angles by single axis hinges. The upper and lower halves of the frame are designed to fold into each other to minimize the folded tray thickness. Two polyethylene sheets, cut to fit into the tray frame, are the "standard" tray modules and may be replaced with other modules, such as the HMMC Extended Vocabulary Augmentative (EVA) Communication Device. The upper and lower trays are connected along the hinge axis by a polyolefin living hinge to provide a continuous surface at any tray angle. Both tray modules are protected from soiling by thin, clear acetate covers.

The tilting and locking mechanisms are located at each side of the tray hinge. The locking action of the mechanism is created by the mating of a spring-loaded internal gear segment in the upper tray frame and an external gear fastened to the stationary lower tray frame. By actuating a brake release at each hinge, the upper half of the tray may be tilted and locked in twelve degree increments over 180 degrees from the fully opened to the fully closed position.

Three different fold-away devices were developed and fabricated. Each device was designed to allow the caregiver to store the modular tray manually at the side of the wheelchair when not in use, without detaching the tray from its wheelchair. The fold-away device features two tubular rails located beneath the tray which guide it from its normal position in front of the user to the side of the wheelchair.

Four prototype trays were fabricated, fitted, and sent out on trial during the first of three assessment phases beginning in the Fall of 1986. Technical and clinical assessment will be conducted for each tray system dispensed. Results of the assessment will be available in 1987.

Preliminary Results—Seven subjects have been fitted with modular tray prototypes. Preliminary results of caregiver and technical assessments indicate that the tilting operation was well received; however, further development of the wheelchair interfacing hardware is required. Final results of the evaluations are not yet available.

PACA—Portable Anticipatory Communication Aid

**Craig W. Heckathorne, M.S.E.E.; Dudley S. Childress, Ph.D.; Lew J. Leibowitz, B.S.E.E.;
Jerrilyn A. Voda, M.S., C.C.C.S.P.**

Rehabilitation Engineering Program, Northwestern University, Chicago, IL 60611

Sponsor: *National Institute on Disability and Rehabilitation Research; Easter Seal Research Foundation*

Purpose—The PACA was a research and development project to design a portable computer com-

munication aid which would enhance the communication abilities of non-vocal persons who also have

physical impairments which preclude the use of direct selection techniques. The project had two primary objectives: 1) to augment the utility of traditional scanning communication aids by adding message element anticipation; and, 2) to make this scanning communication aid cost effective to the user by capitalizing on the benefits of the innovative technology and competitive marketing of an available commercial portable computer.

Progress—The PACA communication aid has been completed and is in commercial distribution. It is available as an EEPROM-based program running on the Epson HX-20 portable computer. The program configures the Epson's features to support person-to-person (conversational) communication,

note taking, writing, and math calculations. Two operational versions of the program are available: a single-switch automatic scanning version and a two-switch step-scanning version.

A major emphasis of the PACA program is the use of anticipatory (predictive) algorithms, which on the average reduce the number of scanning steps and switch activations needed to create a message. The improved efficiency of message creation can result in improved rate of message generation for persons with severe motoric involvement.

The PACA program has been made commercially available through a licensing agreement between Northwestern University and Zygo Industries, Inc. (Portland, Oregon), a manufacturer of electronic communication systems.

Available Motions of Hand, Mouth, and Head Stick Users: Applications to Keyboard Designs

Everett Johnson; Ray Smith; Georgios Yiallovros; Adisak Mekittikul

Rehabilitation Engineering Center, Cerebral Palsy Research Foundation of Kansas, Inc., Wichita, KS 67208

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The purpose of this project is to develop techniques for measuring head and neck motion; to provide a measurement system and head-motion data to support basic research in head motions; and using the information obtained, to develop keyboards for use by persons restricted to activating keys with head, hand, or mouth sticks.

The advent of the personal computer (PC) has provided the severely handicapped person with the means of communicating, controlling the environment, and even gainful employment. The category of handicapped persons this project addresses are those who, as the result of neurological impairment, cannot use a standard keyboard in the way it was designed. Persons with this type of handicap are restricted to activating the keyboard one key at a time, with a single digit, i.e., finger, hand stick, mouth stick, or head stick. Various techniques, such as the use of positioning templates, have been designed to improve the handicapped person's use of a standard keyboard. Persons forced to use a head stick are the primary target of this effort.

Progress—The methodology involves the determination of motion capabilities of the handicapped

population. Efforts were directed toward determination of the range of motion of the neck and head. The range of motion of the tip of a head stick is a function of its length and the range of motion of the head and neck to which it is attached. Head motion measurements have been taken on able-bodied and handicapped persons. These data have been used to support the keyboard design activity and to provide useful information for fundamental head-motion research. The kinematic model considered here consists of three angular motions: flexion or extension in the sagittal plane, lateral bending in the frontal plane, and the rotation of the transverse plane.

From data related to head motion, it was determined that the ideal keyboard configuration would require the ability to make motions in two dimensions only. The keyboard is called a Two-Degrees-of-Freedom (2DOF) keyboard. The head stick penetrates the vertical keyboard surface in which there are horizontal paths, or key channels, along which keys are located. The user can use the lower part of each horizontal path as a support for the head stick while the next key is sought. The keyboard is transparent to the computer; that is, it can be used

to access any software available to an able bodied user, without requiring modification of the computer.

As a first step, a computer program was written that simulates a single key set of the 2DOF keyboard. The output of the program gives the total distance traveled between keys and the total number of key hits required to type a sample text in English. The distance is measured in normalized units, (normalized with respect to the space between keys). In calculating the number of key hits, only the key hits that initialize each key are considered.

In testing the relative merits of different key combinations, a 4,000 word sample was used as input to a simulation program. For choosing the best key arrangement among those that were promising, a 10,000 word sample was used. The 10,000 word sample was chosen from several sources such as newspapers, magazines, etc.

One of the advantages of the 2DOF keyboard is that each one of its 90 keys can represent up to 16 characters in the form of single words, small phrases, and so on. This feature of the 2DOF keyboard was used to minimize the number of key hits required, by assigning frequently used groups of letters to as many keys as possible. With groups of letters represented by a single key, a word or a small phrase can be typed by using as few as one or two key

hits. Every combination of bigrams, trigrams, and single letters that was thought would decrease the number of key hits was tested, and the more efficient combinations were examined more thoroughly.

Four key sets have been selected for implementation on a pre-production prototype keyboard; general text input, single-key-initiated "WordStar" commands, special characters, and phrases frequently used that can be programmed for an individual user. (The latter keyboard set can be used as a communicator as well as for computer input. Each key selected allows displaying up to 16 characters. Typical phases or words assigned to the keys of key set four are: HELLO, GOOD MORNING, MY NAME IS, WHAT DO YOU MEAN, TAKE ME HOME, or TO THE BATHROOM.)

Results—A 2DOF keyboard appears to be a significant improvement for specialized handicapped user applications. A pre-production model has been fabricated and is currently being operated experimentally.

Future Plans—The development of a production model of the keyboard, documentation, and further study of key placement is proposed for the immediate future.

International Compatibility Standards for Electronic Communication and Interface Devices

Joseph M. Schauer, B.S.; Barry L. Rodgers, B.S.; David P. Kelso, M.S.; Charles C. Lee, M.S.; Gregg C. Vanderheiden, Ph.D.

Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, Madison, WI 53705

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—A set of projects has been underway to develop compatibility standards for electronic communication systems and user-interface devices. Providing compatibility between devices from different manufacturers increases the ability of persons with disabilities to use appropriate aid systems, and makes it easier for educators and clinicians to evaluate, prescribe, and apply equipment and software from different manufacturers.

Progress—The Trace Center has been involved in:

1) developing compatibility standards; 2) working with manufacturers to implement compatibility standards; and 3) supporting national and international standards organizations considering the standards or developing adaptations for international use. These proposed standards are developed with continual feedback from interested manufacturers, clinicians, researchers, and users in North America, Europe and Australia. Proposals have been written to establish standards for Simple Electrical Transducers and Serial Code, Keyboard Emulating Inter-

faces, Morse Code and Input Selection Arrays. Proposals for Serial Interface Control for Powered Wheelchairs, and Infrared Environmental Controls, are under development.

Computer Accessibility: Support of the Industry/Government Initiative

Gregg C. Vanderheiden, Ph.D.; Charles C. Lee, M.S.; David P. Kelso, M.S.

Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, Madison, WI 53705

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—This project supports the efforts of the Industry/Government Initiative which brings together computer manufacturers, developers, and consumers in order to give disabled individuals better access to standard computer hardware and software systems.

Progress—The project was started in 1984 to support work by the White House, the Office of Special Education and Rehabilitation Services (OSERS), and the National Institute on Disability and Rehabilitation Research (NIDRR). A committee of computer manufacturers, including Apple, AT&T, Digital Equipment Corp., Hewlett Packard, Honeywell, IBM, and Tandy (Radio Shack), as well as representatives from government agencies, research groups, rehabilitation manufacturers, and disabled individuals, have been involved in the project.

In 1985, a “white paper” was completed at the request of the computer industry. This paper carefully discussed the problems faced by persons with disabilities, examples of solutions, and the difficulties with implementing various strategies. A videotape illustrating state-of-the-art computer accessibility was produced that included clips from computer access centers around the country.

In 1986, several versions of a document outlining “Considerations in the Design of Computers” (formerly “Guidelines”) were completed. This document, which reflected the combined input of industry, researchers, and consumers, provided a revised

Publications Resulting from This Research

Keyboard Emulating Interface Compatibility Standard Proposal 4.0 Version 1. Rodgers BL, Schauer J, 1986.

summary of the problems, populations affected, the priorities, and possible solution strategies.

In 1987, members of the Task Force provided input to the National Institute on Disability and Rehabilitation Research (NIDRR) and General Service Administration (GSA) during the development of procurement guidelines to increase the accessibility of electronic office equipment. The Task Force contributed ideas and expertise from its earlier work and provided specific review of NIDRR and GSA proposed guidelines.

Results—This project has resulted in facilitating the computer industry in their consideration of design and manufacturing of products to optimize the access of computers to persons with disabilities by highlighting need and suggesting economical and feasible design ideas.

Publications Resulting from This Research

Computer Accessibility Considerations. Vanderheiden GC, Lee CC, Scadden LA, *Proceedings 10th Annual RESNA Conference*, 7:750-752, San Jose, CA, June 1987.

Advance Executive Summary of the Considerations Document Version 2.0. Vanderheiden GC, Lee CC, 1987.

Considerations in the Design of Computers and Information Processing Systems to Increase Their Access by Persons with Disabilities Version 2.0. Vanderheiden, GC, Lee CC, April, 1986.

White Paper: Access to Standard Computers, Software, and Information Systems by Persons with Disabilities Version 2.0. Vanderheiden GC, 1985 Revision.

Computer Access for Disabled Individuals. (VHS Videotape). Brandenburg S (Script Writer & Ed.), 1985.

ALTKEY: A Multi-Mode Input Program for the IBM-PC

Lincoln A. Jaros, B.S., and Simon P. Levine, Ph.D.

Rehabilitation Engineering Program, Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center, Ann Arbor, MI 48109

Sponsor: Rehabilitation Engineering Program, Department of Physical Medicine and Rehabilitation, University of Michigan

Purpose—Many handicapped users have special problems which must be solved in order to give them access to the full power of a computer. Many types of disabilities prevent a user from effectively controlling the computer through the standard keyboard. These users must be able to use one or two special switches to reproduce the wide variety of keystrokes available on the keyboard and/or develop means for increasing input rates. The IBM-PC and PC-compatible computers have established themselves as the standard personal computers in business and industry, which together with their capabilities and steadily decreasing costs, have made them an excellent choice for handicapped users. The purpose of this research project is to develop a comprehensive programmable input system for the IBM-PC which can function in a wide range of modes (e.g., scanning, coding, Morse code, etc.).

Previous work has included basic development of ALTKEY, a memory-resident computer program for the IBM-PC, designed to fulfill these objectives. ALTKEY augments the device driver software already present in the basic input/output system read only memory (BIOS ROM). Input generated by this system goes to the regular keyboard buffer where it is treated as actual keyboard data. The first mode developed was a scanning system, allowing each user to design and edit individualized scan menus. In the scanning mode, the user is presented with a series of input choices listed across one line of the video screen. These choices are highlighted one at a time in a repeating pattern. The user makes a specific choice by activating a single switch when the desired entry is highlighted. The switch can be one of the shift keys on the keyboard or a momentary switch connected to a game port input. Each selection can display a new set of choices or send key codes to the keyboard or both. The list of branching menus and entries is called a Scan Tree. The Scan Tree is defined in a simple text file called a Scan Tree Definition File. The user can create and edit these files, customizing them for specific application programs. The flexibility of the tree design allows

required selections to be minimized by presenting the user with the most likely choices first.

Progress—Morse code capabilities have been added to ALTKEY. At any point in the Scan Tree described above ALTKEY can be programmed to shift into a Morse code entry system. For an experienced user, this can increase the speed of general text entry significantly. Combining the two data entry modes allows complex or lengthy keyboard sequences to be generated with a Scan Tree, while random text entry can be expedited with Morse code.

Another new feature of the program is the Hold Item. The Scan Tree can be programmed so that holding the selection key down for a set period of time activates some action. This feature is always active (in both scanning and Morse code modes) so that it can be used to prevent the user from becoming stuck in some unexpected loop. When this happens the user can re-boot the computer by holding down the selection key for five seconds (or any other predefined time period).

Future Plans/Implications—ALTKEY currently has only one type of scanning scheme. This single-switch protocol is explained above. In the future, the program may be expanded to allow the use of two, three, or four switches for schemes that would afford some users greater speed. For example, one switch could be used to advance the highlighted scan item while a second switch could be used to make a selection. By using four switches it would also be possible for a user to make a direct selection from a scan menu of four items.

Publications Resulting from This Research

A Single Switch Keyboard Emulator for the IBM-PC. Jaros LA, Levine SP, *Proceedings of the 8th Annual Conference, IEEE Engineering in Medicine and Biology Society*, 1823-1825, 1986.

ALTKEY: A Special Input Program for the IBM-PC. Jaros LA, Levine SP, *Proceedings of the 10th Annual RESNA Conference*, 7:714-716, San Jose, CA, June 1987.

Assessment and Prescription of Writing Aids for Physically Handicapped Children

S. Jarvis, B.Sc.(P.T.) and R. Lanno, B.A.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: Research Department, Hugh MacMillan Medical Centre

Purpose—This study proposes to prescribe writing aids for a small number of students with difficulties in writing skills: to provide these students with training in the use of these aids and to assess the efficacy of the prescription.

Progress—Five Ontario school students, from our out-patient population, are included in this study. Each student has a basic language capability to read and understand print. However, these students have difficulty producing acceptable written work in school. The students were administered the following tests: 1) Stanford Diagnostic Reading Assessment (SDRA) Test Form A (Levels Red and Green) to check functional reading levels; 2) Bruininks-Oseretsky Test of Motor Proficiency (Bruininks, 1978); and 3) North York Self Concept Scale, primary level (Crawford, 1977; Cassidy, 1974; Cassidy and Brooks, 1978).

In addition, the students performed the following writing tasks: 1) Name, address, telephone number, age, school; 2) Copy from text (timed for 5 minutes); 3) Spelling (at grade level); and 4) Sample of classroom written work (obtained from teacher).

The student, teacher, and parent(s) were interviewed. Students were assessed and prescribed a suitable writing aid (computer with printer) and word processing software program. Commodore 64, the word processing program Bank Street Writer, was used. All but one of the students and teachers received training in the use of the writing aid at

school until the student reached an independent capability. The remaining student and mother received training at home. Up to twelve sessions of 45 minutes duration were given.

The students then used the writing aid for approximately four months. The occupational therapist provided Student/Teacher support in bimonthly visits to the school or the home during this time.

Preliminary Results—All but one of the students were able to independently access the computer. At the end of the trial period (4-5 months), the initial assessments were repeated. The writing tasks have yet to be completed and will be performed with the computer. Non-parametric t-test (Walsh test) of pre- and post-measure for the SDRA, Bruininks, North York Self Group and the writing tests will be performed. Information has been requested of the teachers and parents concerning the use the child has made of the computer.

Future Plans/Implications—All but one of the children in this project attended a school for the physically handicapped. Further research should assess the needs of writing aids for children with writing problems attending the public school system. The question of whether computers or electronic typewriters best suit this type of child, and the environment in which they function, remains to be investigated.

Evaluating the Effectiveness of Direct Client Intervention and Facilitator Training in Communication Intervention with Nonspeaking Physically Disabled Children: Pilot Study

P. Parnes, B.Sc., D.S.P.A.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: Research Department, Hugh MacMillan Medical Centre

Purpose—The goal of the pilot research project was to evaluate, through successive implementation, the effectiveness of a two-phase intervention program

on the communicative interaction of a nonspeaking physically disabled child and his primary facilitator. The intervention program involved direct service

intervention with a nonspeaking child; and then, training for his primary facilitator.

Progress—The research project was a pilot study and involved a single dyad. The child was a four-year-ten-month-old boy with a diagnosis of cerebral palsy with severe spastic quadriplegia. The primary facilitator was the child's mother. The study involved the following stages: baseline prior to intervention with the child; and the addition of facilitator training on a group and individual basis. The first phase of the study involved direct intervention with the child during two half-day sessions over a two-week period. Issues addressed during direct intervention with the child were as follows: the introduction of adaptive toys operated by a single switch; the introduction of an initial augmentative communication system (i.e., a portable picture communication display); the development of appropriate means to access the display; the development of strategies to request attention, to request assistance, to request information and to initiate topics; and the provision of consistent feedback to confirm or reject the partner's interpretation of messages.

The second phase of the study involved intervention directed toward the child's mother on an individual and small group basis. Individual facilitator training occurred during two half-day sessions over a two-week period. The sessions involved informal discussions and modeling of the following interaction strategies: providing choices to the child; responding to the child's lead; pausing; developing interaction on novel topics; asking appropriate questions; and modeling the use of the child's augmentative communication systems. In addition to the individual sessions, the mother also attended a one-day workshop on Establishing Basic Communication Skills offered by the Augmentative Communication Service (ACS). The workshop involved approximately ten participants in group discussion and problem-solving related to issues in facilitating communicative interaction with non-speaking individuals.

The child and his mother were videotaped for a ten-minute period in an unstructured free play situation on three separate occasions: 1) baseline; 2) following intervention with the child; and 3) following facilitator training. The videotaped interactions were transcribed and coded through a detailed system of analysis developed by Light (1985). In sum-

mary, the interaction was analyzed with respect to the following three variables: 1) the discourse status of the turn; 2) the communicative function; and 3) the mode of communication. Data were analyzed for mother and child variables across each of the three stages of intervention to determine the cumulative effects of the program.

Results—Results of the study indicated that the intervention program affected the child's modes of communication, his communicative functions and his discourse status. In general, the child assumed a more active role in the interactions following intervention: he initiated more topics, made more requests for objects and activities, and issued more feedback responses to confirm or deny his mother's interpretations of his messages. The intelligibility of the child's communicative turns increased over the two-phase intervention program, as did his use of his communication board and his use of gestures as a means to augment his communication.

The two-phase intervention program also significantly affected the mother's modes of communication, her communicative functions and her discourse status. Following intervention, the mother provided more models of communication board use for the child. She seemed less concerned with directing her child's behavior and more concerned with encouraging his active participation in the interaction. In general, the mother showed increased responsiveness to her child following intervention.

The greatest changes in the mother's interaction patterns were effected at stage three following facilitator training on a small group and individual basis. Changes in the child's interaction patterns, however, were effected successively across stages two and three. While the direct client intervention (stage two) served to enhance the child's interaction strategies, the facilitator training (stage three) and the resulting changes in his mother's interaction strategies allowed him increased opportunities for communication within the interaction.

Publications Resulting from This Research

The Effect of Communication Intervention with Nonspeaking Physically Disabled Children. Light J, Rothschild N, Parnes P. Paper presented at *The American Speech Language and Hearing Association Annual Convention*, Washington DC, 1985.

COGORTH: Cognition Orthosis Programming Language

Lincoln A. Jaros, B.S.; Simon P. Levine, Ph.D.; Ned L. Kirsch, Ph.D.

Rehabilitation Engineering Program, Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center, Ann Arbor, MI 48109

Sponsor: Robert Wood Johnson Foundation, Princeton, NJ

Purpose—Patients who acquire diffuse and/or focal lesions of the brain often sustain dramatic and potentially debilitating changes of cognitive functioning. A technique for assisting such patients to function independently using a computerized cognition orthosis has been developed. It has been successfully used to guide brain-injured patients through tasks which they could not otherwise perform unaided (see “Computerized Task Guidance for Cognitively Impaired People,” elsewhere in this issue).

This report describes some of the features of the programming language called COGORTH (from COGnition ORTHosis), specifically designed for the development of computerized cognition orthoses.

Progress—COGORTH is a specialized computer language providing a highly structured environment for providing cues and programming sequential messages. These cues and messages can be used to assist patients who need guidance for the completion of complex activities. Current capabilities permit message presentation on a video display and the use of audio or visual cues such as computer-generated musical tunes or flashing room lights. A COGORTH program (called an Instructional Module) can display directions to a patient and then make decisions about future actions based on the patient's response.

COGORTH provides Instructional Module programming capabilities which can: a) check a patient's performance for errors and time compliance; b) branch to error correction or extended help procedures when necessary; c) provide guidance for multiple concurrent tasks; d) allow a task with higher priority to interrupt less important tasks; e) control electrical devices in a patient's environment.

Instructional Modules are simple text files which may be created and updated with any text editor. Although COGORTH is an interpreter, it permits the use of library files for the inclusion of user-defined functions and routines. It is envisioned that COGORTH will be used by health professionals

having a wide range of programming skills. Careful consideration has been given to balance the power and complexity of the language with the need for simplicity.

Preliminary Results—The original version of COGORTH was written in C and implemented on the Apple II. Two years ago, it was ported to the IBM-PC and has since undergone significant enhancement. Recent additions allow the language to handle much larger IMs (Instructional Modules) with greater speed. Several important changes to the control structure have been incorporated. These include an “ELSE” option for “IF” statements and parameter passing in subroutine calls. The programmer now has the choice of displaying messages using large graphics characters appropriate for visually impaired patients. The language can use either of two commercially available environmental control units to turn lamps and appliances on and off. It can now also play musical tunes using the system speaker as opposed to just producing simple monotones.

Future Plans/Implications—The evolution of the COGORTH language is an ongoing process. The motivating force behind this change is the continuing computerized task guidance research for which it was designed. Additions in the near future will be: improved automatic storage of performance measures recorded for later analysis and synthesized voice output for audio presentation of messages. Longer range plans call for adding a user-friendly front end to the program. This front end would be designed to help a new programmer to easily understand and use COGORTH language features.

Publications Resulting from This Research

COGORTH: Cognition Orthosis Programming Language. Levine SP, Kirsch NL, Jaros LA, *Proceedings of the 7th Annual Conference, IEEE Engineering in Medicine and Biology Society*, 700-702, 1985.

COGORTH: A Programming Language for Computerized Cognition Orthoses. Jaros LA, Levine SP, Kirsch NL, *Proceedings of the 8th Annual RESNA Conference*, 5:359-360, Memphis, TN, 1985.

Application of Technology to Enhance the Employability of Severely Communicatively Impaired Individuals

Elizabeth J. Allen, Ph.D. and Andrew Y.J. Szeto, Ph.D.

Assistive Device Assessment Program, Clinical Training Center, San Diego State University, San Diego, CA 92182

Sponsor: U.S. Department of Education—Office of Special Education and Rehabilitation Services

Purpose—Employment for persons with severe disabilities is often an unfulfilled dream. One of the major barriers to successful employment for this population is adequate communication for the workplace. Although computer technology has augmented the potential communication skills of the person with physical disabilities, little attention has been given to resolving communication problems related to entering and retaining employment. Therefore, the purpose of this demonstration project has been to develop a multidisciplinary approach for analyzing the communication needs of a client in a particular workplace; for prescribing and customizing an appropriate communication system for that client; and for training that client to have communication competence for the workplace. The removal of the communication barrier to employment would provide greater independence as well as economic and psychosocial benefits for the person with disabilities.

Progress—An important feature of this project has been the development of rapid, targeted, assessment procedures. Utilizing this approach, it has been possible to identify the type of augmentative communication device needed by a client after two or three 2-hour visits to the Clinical Training Center on the San Diego State University Campus.

The targeted assessment procedures begin with a comprehensive preassessment evaluation conducted by the multidisciplinary Assistive Device Assessment Program (ADAP) team. The critical elements of this evaluation are a screening interview with the referring individual, a detailed application form, and written reports from the potential client's physician and other agencies providing professional services. Based on this information, the ADAP team decides whether to accept the client and, if so, what additional information is needed. The team social worker then gathers the needed information through additional collateral contacts, one or more home visits, and (if relevant) visits to the client's school or sheltered workshop.

The application materials and the social-work

report enable the speech and language pathologists on the team to plan a cognitive/communication assessment that utilizes parts of various standardized tests as well as a variety of informal measures specially chosen for the particular client being assessed. This assessment constitutes the first of the two on-campus evaluations.

The results from the cognitive assessment are used to guide subsequent evaluations of the client's physical/technical skills and vocational potential. The physical/technical assessment procedures encompass gross and fine motor skills, the client's ability to operate keyboards and switches, and the best anatomical control site in terms of accuracy and speed. Following this assessment by the team rehabilitation engineer, the client is evaluated using communication devices (either directly or through simulation) to determine which devices are suitable for the client.

The Vocational Placement Phase has been the most difficult aspect of the demonstration project for three main reasons: 1) the clients referred to and accepted into the project have not been considered as having any vocational potential because of their severe disabilities; 2) funding for communication devices is limited or unavailable for most project clients; and, 3) there are few employment sites open for clients with severe physical and communication disabilities.

Not only have many project clients not been vocational rehabilitation clients, they also have not even been in vocational preparation programs. Therefore, considerable effort has been expended to prepare clients for employment. Although third-party funding of communication devices has always been problematic, funding of devices for individuals who acquired head injuries after age 18 is particularly difficult, since these clients often are eligible for only acute-care services. Even when a client does acquire a communication device and has been prepared for partial employment, the client may not have an opportunity to work. In addition to the usual employer apprehensions about disabled employees, many employers are not aware of recent

technological developments that can facilitate work performance or communication. Consequently, these employers do not consider hiring individuals with severe disabilities.

Progress—The project team developed several approaches to overcome some of these difficulties. They include the following:

1) Training clients to use the recommended device on a regular basis in order to document the appropriateness of the device for communication and employment.

2) Working with representatives of various community agencies to develop their awareness of a client's vocational potential, when given an effective method of communicating at the worksite.

3) Developing new routes to the workplace for clients. Some of the more promising avenues include placement in sheltered workshops, individualized vocational training programs, and supported work. Each of these approaches has required considerable investment in time and energy from the ADAP team and various community agencies.

All of the accepted clients have completed their cognitive and physical/technical assessments for using a communication device. Currently, six project clients are undergoing some type of training for improving their communication competence and/or vocational potential. Two of these clients have secured and are actively using an appropriate electronic communication system, and 13 clients are being processed for device funding. Seven clients are in the vocational phase of the project, with three being processed by Vocational Rehabilitation and four placed into a suitable vocational situation.

Although Federal funding for this project ended in September 1987, clients who have not yet acquired a communication device or are still in the vocational phase will continue to receive project support through

the clinical practicum associated with the Assistive Device Assessment Program.

Results—In spite of the difficulties encountered, the demonstration project has been very worthwhile in several respects. The project provides a much needed community service, one that is unavailable elsewhere in the area. Another benefit is the active involvement of graduate students on an interdisciplinary team. This practical clinical experience has expanded their problem-solving skills. Third, the project has demonstrated that a complex process can be achieved through targeting assessment procedures. In addition, the project's efficient assessment procedures have been successfully used to support the procurement of much needed communication devices for several of the clients. Lastly, the project has clarified several important issues that affect employability enhancement through technical communication devices and the translation of that enhancement into vocational rehabilitation of severely communicatively impaired individuals.

While the demonstration project has benefited clients and the ADAP team members, it also identified two major problems: 1) members of vocational rehabilitation agencies and employers have a very limited awareness of technological applications to enhance communication and employability; and 2) the processes of acquiring communication devices, training device competency for employment, and developing work skills are very time consuming (often a year or more in length) and require an extensive network of resources. Resolution of these problems involves more public education, increased funding for communication devices, reduced eligibility requirements for client populations, and more rehabilitation programs that focus on the client with severe disabilities.

A Model for the Assessment of the Written Communication of Nonspeaking Physically Disabled Individuals Who Use Microcomputers

S. Kelford, B.Sc. and S. Thurston, B.Math.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: *University of Toronto, Speech Pathology Alumni Association; Research Department, Hugh MacMillan Medical Centre*

Purpose—The objective of this research study was to develop a model to systematically describe the

process of written communication by nonspeaking physically disabled individuals who use computers.

Specifically, the goals of the research were: 1) to systematically describe the form, content, and use of written communication by a small number of nonspeaking physically disabled individuals who use microcomputers; and, 2) to determine the principles and guidelines necessary to objectively assess the process of written communication by this population.

Progress—Ten subjects and their facilitators participated in the study. The subjects were divided into two groups: Group A were 8 to 10 years of age and used Blissymbols as their written communication system; Group B were 14 to 23 years of age and used traditional orthography in their written output. All of the subjects were congenitally physically disabled; had sufficient cognitive ability to permit written communication; had receptive language skills functional for daily needs; had hearing and vision (or corrected vision) within normal limits; used an augmentative system for face-to-face communication and a microcomputer for written communication in the home.

Spontaneous written output completed in the home over a 28-day period was collected from each subject. For each written sample, information regarding the intended purpose and audience, the subject matter, the amount and nature of any help provided, the length of time invested and the relative quality of the written output was obtained from the facilitator and/or subject. Each individual's writing was then described according to a coding system designed to determine the function, form, and content.

Results—Results indicated that the subjects spent a considerable amount of time writing. They composed the majority of their productions independently, and wrote for a variety of different purposes and intended audiences. The subjects demonstrated considerable facility in the form and content of their written productions. There was considerable variation across subjects within each group, as well as considerable intra-individual variation day to day.

Development of a Toy Control Program for the Apple IIe

Rob E. Garrett, B.Tech.

Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, Kilkenny, S.A. 5009 Australia

Sponsor: *None Listed*

Purpose—Young children with disabilities need an appropriate reward to encourage them to develop switch access skills. A single switch is connected to the Apple IIe games port and the Apple output is used to turn a toy on or off. The Apple Toy Control Program enables a therapist to select an input switch protocol suitable for the child. Current modes are: press on/press off, press more than N times, press N times, hold for more than T seconds and hold and release after T seconds. Successful completion of the task causes the toy to run for a pre-set time.

Progress—The current version of the program is

currently being tested within Regency Park Centre for Young Disabled and a printed circuit board is being developed so that production costs will be low.

Preliminary Results—Children tested so far show high motivation to develop the required switch access skills.

Future Plans/Implications—This program, along with interface hardware and a user manual, will be available from Regency Park Centre for Young Disabled by January 1988.

D. Private/Public Programs

Development of the Occupational Therapy Comprehensive Functional Assessment (OTCFA)

Roger O. Smith, MOT, OTR; Ken Ottenbacher, Ph.D., OTR; Roann Barris, Ed.D., OTR
Trace Research and Development Center, Madison, WI 53705

Sponsor: *American Occupational Therapy Foundation*

Purpose—In early 1970, the American Occupational Therapy Association acknowledged the significant inconsistency and splintered approach of assessment in occupational therapy. At that time it began sponsoring research to evaluate the significance of the problem and implement some strategies for assuring a better continuity of evaluation between service delivery settings and instituting a more comprehensive approach for evaluating the efficacy of therapeutic intervention. The most recent step in the development of a better comprehensive performance evaluation has been the formulation of the constructs and content in the Occupational Therapy Comprehensive Functional Assessment (OTCFA).

Progress—Within the past year, the project has refined the constructs and content for the assessment. Occupational therapists throughout the country, representing all the service delivery areas of occupational therapy, have been intimately involved in providing discussion and feedback to the project team. Consequently, the early phases of the OTCFA development have been extremely iterative with multiple revisions of the OTCFA instrument. The belief has been that without a solid construct and content foundation, application would be extremely limited.

Preliminary Results—The overall conceptualization is a hierarchical model of functional performance. This model is unique in that it integrates 1) high level activity functions such as basic self care activities, home making activities, vocational and

avocational, with 2) the integrated skills which are necessary to adequately perform the activities, with 3) the component abilities which provide the basic elements to achieve the skills necessary to perform the activities. In this conceptual model of functional assessment, not only is it able to highlight a specific activity with which an individual is having problems, but also what sets of skills are major contributors to the difficulties in activities. The environment is viewed as a second dimension as opposed to simple categories within the performance areas, because all social, cultural, and physical environmental factors do not stand alone, but directly affect performance on all levels.

Future Plans/Implications—The full scale OTCFA includes five levels, fourteen major areas, and 117 detailed categories of function. The implications of OTCFA are many including the comprehensive assessment strategy of patients which occupational therapist treat, a documentation scheme for medical records, a technique for converting functional assessment data into treatment planning information, a framework for education curricula, and an organizational scheme for research in the field.

The OTCFA project team is currently piloting the instrument. It is anticipated that the nationwide pilot studies' subsequent revision of the instrument, development of instructional and administrative materials, and identification of test/retest and interrater reliability, will be completed in 1988. Computerization of this instrument to increase its utilization is in the planning stages.

Improving Management of Vocational Rehabilitation Services

Joseph B. Moriarty; Don E. McLaughlin; Ranjit K. Majumder; David A. Molinaro

West Virginia Rehabilitation Research and Training Center, West Virginia University, Morgantown, WV 26506

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—In recent years NIDRR's interest in and emphasis on improving vocational rehabilitation (VR) management has resulted in the West Virginia Rehabilitation Research and Training Center (WVRRTC) focusing its efforts primarily in that area. The Center's goals are to: a) study management theories, principles, techniques, and models; b) adapt those established entities to VR management where profitable; c) research and develop new approaches where needed; and, d) devise management procedures which are tailored to the unique needs of the VR program, and capitalize on the use of information technology to support and facilitate the management practice. Studies have been designed as 12 research projects, 5 training (utilization/dissemination) projects, and 6 special initiatives or ancillary activities.

Progress—Three research projects are currently underway to analyze decision behavior and to provide decision support in the VR setting. Client decisions are being studied in the context of vocational goals and economic future (R-1). Counselor decision making processes are being studied from the point of view of information needed and the use of technology to access and display information to facilitate decision making (R-2). Investigation of agency managers' decision processes focuses on databases of program statistics, program evaluation, and program performance.

In order to develop an integrated decision support system with information files, information processing, and information display relevant to VR management, the Center has postulated a contextual framework: what kinds of clients, with what kinds of characteristics, in what environment, receive what kinds of services, at what cost, leading to what outcomes? Five interrelated projects are in process to accomplish the goal of designing a comprehensive decision support system.

Finally, planning, both short and long range, plays a critical role in management. This process of targeting efforts and the means of achieving them is the focus of three of the Center's current projects on improving management.

Results—Project R-1 is nearly complete. Intensive structured interviews with VR clients were conducted and the resulting data compiled, organized, and validated. All that remains to be done is the preparation of reports showing the correspondence between micro-economic theory of utility and VR client responses to economic decisions, and reports indicating the application of client decision making to VR program and practice. For the R-2 project most of the necessary computer software, consisting of 12 separate components, has been developed and is either being field-tested or being revised as a result of previous testing. Current plans are for a few new programs and the implementation and evaluation of the total counselor information support package. Project R-3 necessitated the development and distribution of a survey questionnaire to obtain a comprehensive picture of the present management practices of VR agencies.

Future Plans/Implications—Plans call for an intensive analysis, a synthesis of management theory and practice, and information to the agencies. To carry out Projects R-5 through R-9, WVRRTC developed a comprehensive survey questionnaire which was distributed to 5,400 managers in VR at the different levels of hierarchy. In addition, in an accomplishment unique in VR research, four separate databases from the Ohio VR agency were merged. Tabulation and analysis of the resulting data has been completed. The production of a summary technical manual, the development of a computer program allowing managers to interactively examine combinations of factors as they contribute the key outcomes, and the national dissemination of the decision-support system prototype are all in the plans for the coming months.

Projects concerned with planning have involved: a) mathematical modeling of rehabilitation indicators over time; b) establishing relationships between the superstructure, infrastructure, and performance of VR programs; and, c) models of selection, skill development, and effective deployment of personnel.

Progress Report for the PEER Regional Network

Robert J. Rosati, Ph.D.

Human Resources Center, Albertson, NY 11507

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—The PEER Regional Network is designed to promote the use of proven, effective programs and practices among educators and rehabilitation professionals. The project is a resource for any individual or organization providing services in Rehabilitation Services Administration Region II (New York, New Jersey, Puerto Rico and the Virgin islands). Using a specific, uniform evaluation, the PEER Regional Network validates selected programs, formally recognizes those that are exemplary and provides technical assistance to organizations seeking to replicate exemplary program models.

The current focus of the PEER Regional Network is on programs that provide either transition or supported employment services to youth with disabilities. Special efforts are being made to validate and formally recognize programs that are serving individuals with learning disabilities and those that are in least restrictive environments.

Progress—During the first year of the project, efforts focused on developing a system which would identify exemplary programs and practices on the basis of documented outcomes. As part of this process, an advisory board of State Directors, Advocates, Researchers and Trainers was recruited to give direction to the project and eventually participate in the selection of exemplary programs.

After an extensive review of the literature and input from the advisory board, a detailed program validation questionnaire was developed. The project is in the process of validating approximately 14 transition programs. By September of 1987, data

from these programs was forwarded to the PEER advisory board. Upon selection of the exemplary programs, site visits will occur to further document program components.

Preliminary Results—A major component of this project is the dissemination of information. Dissemination involves informing those in the field of the purpose of the PEER Regional Network as well as highlighting programs identified as exemplary. During the first year, the major focus was on disseminating information about the project. This was accomplished through the development of a brochure and other print materials.

Future Plans/Implications—Following the identification of exemplary programs, the project will enter its technical assistance phase. The project will encourage exemplary programs to provide technical assistance, with the support of the PEER Regional Network, to other programs interested in adopting innovative service delivery components. This technical assistance should help to improve the adopter program.

One of the most significant features of the PEER Regional Network is its flexibility to respond to the needs of the field. The project is set to work in any priority area specified by the funding agency. Although the project is currently working with transition and supported employment programs, this emphasis could be expanded in future years. However, the project will continue to validate programs in all previously identified priority areas.

Program in Social and Independent Living Skills

Robert Paul Liberman, M.D.; Gayla Blackwell, R.N., M.S.W.; Charles J. Wallace, Ph.D.; Thad Eckman, Ph.D.

Rehabilitation Medicine Service, Brentwood Division, West Los Angeles Veterans Administration Medical Center, Los Angeles, CA 90073

Sponsor: National Institutes of Health

Purpose—The objectives of this program are to develop, evaluate, field test, and disseminate a

comprehensive set of "modules" for use by mental health and rehabilitation practitioners in teaching

social and independent living skills to severely and chronically ill mental patients. The skill-building techniques are designed to remediate the deficits that prevent patients from attaining successful community adjustment and improved quality of life.

The training technology is organized and designed to maximize its exportability and utilization by service providers in a variety of clinical and applied settings—hospitals, day treatment centers, mental health clinics, residential care facilities, and family homes. The training methods are packaged with highly specific instructional materials in a “module” that consists of a trainer’s manual, a patient’s workbook, and a demonstration video. The video provides models to highlight the skills to be learned and helps to overcome the cognitive deficits and learning disabilities that are so frequently found with major mental disorders.

Progress—Modules have been developed in several skill areas including “Medication Management,” “Recreation for Leisure,” “Grooming and Self-Care,” “Social Problem Solving,” and “Symptom Self-Management.” The modules are designed to have patients and staff engaged in an educational process that promotes: 1) practicing the skills that constitute the module in the treatment setting and in the community; and, 2) learning how to solve problems that patients are likely to encounter when using the skills in real-life situations.

The skills are taught using a combination of videotaped demonstration, motivational interactions to ensure active participation by patients, question/answer exercises, roleplays, *in vivo* exercises, and homework assignments. The trainer or therapist takes an active role in prompting and coaching patients to make successive approximations to improved competencies. Each module takes approximately 30-40 hours to complete, depending upon

the patient’s level of functioning and educational readiness. To contribute to improved clinical outcomes, the modules must be imbedded in a comprehensive treatment program including case management, crisis intervention, pharmacotherapy, liaison with psychiatrists, and other rehabilitation services.

During the past year, the “Medication Management” module was field-tested extensively in over 35 representative clinical facilities throughout the USA. It was found that the module could be readily utilized by diverse staff, with reasonable fidelity in delivering its components, without more training than a brief workshop and follow-up telephone consultation. Patients were able to learn the knowledge and skills involved in self-management of their medication and compliance to medication regimens improved.

Future Plans—Future research efforts will be directed toward evaluating, field-testing, and disseminating the modules that have been developed. Each module will be evaluated with respect to: 1) *skill attainment*, the degree to which patients are able to successfully demonstrate that they have acquired the requisite skills of the module; and 2) *treatment outcome*, the extent to which the requisite skills are maintained by the patient and generalized to the natural environment.

Several of the modules are being evaluated in the context of a 5-year research grant, funded by the National Institute of Mental Health, to determine whether skills training yields improved outcomes (e.g., less relapse, better psychosocial functioning, higher quality of life, lower maintenance neuroleptic medication requirements) in conjunction with a low dose maintenance antipsychotic drug regime. During the next year new modules for training “Conversation Skills” and “Money Management” will be designed.

Advances in Psychosocial Rehabilitation

The Rehabilitation Research and Training Center

Department of Psychiatry and Behavioral Sciences, George Washington University Medical Center, 613 Ross Hall, 2300 Eye Street, N.W., Washington, DC 20037

Sponsor: National Institute on Disability and Rehabilitation Research

Background—For several decades researchers and practitioners, and particularly the clients themselves, have recognized that psychological and social factors play a central role in the successful rehabilitation of physical disabilities. During the past two decades there have been promising starts in conceptualizing psychological and social processes common to such disabilities as paraplegia, deafness, blindness, cancer, coronary artery disease, etc. However, it has been difficult to mobilize sustained, programmatic research and training in

this area of rehabilitation. Recognizing this lack, the National Institute on Disability and Rehabilitation Research has funded a new center to develop specific research programs and training efforts that will enrich and further define the field of psychosocial rehabilitation. The Rehabilitation Research and Training Center at George Washington University was chosen for this task. The series of five manuals summarized below provide a report on this work, which advances considerably the field of psychosocial rehabilitation.

Developing a Clear Image of the Family: The Card Sort Procedure as an Easy and Precise Method for Measuring Family Process in the Rehabilitation Setting

David Reiss, M.D., and Mary Ellen Oliveri, Ph.D.

Purpose—Family images and rehabilitation. This manual describes in detail a relatively new process for precisely measuring family interaction process. What is the relevance of such a procedure for ordinary rehabilitation practice? There are three fundamental reasons why we present this procedure to the rehabilitation community at this time: i) The family plays a major role in rehabilitation outcome for children and adults; ii) The family is often difficult to assess: it remains important but “invisible”; iii) The procedure for “imaging” the family described in this manual has now been tested with hundreds of families in many settings here and abroad and is clearly ready for more widescale use.

Progress—Family researchers have developed methods of directly observing families in action under standardized conditions and are using precise methods for quantitative measurement. This type of assessment has two forms. The first encourages family members to talk among themselves, either in their home setting or in a research setting. Their interaction may be audio- or video-recorded and

then coded with standardized, reliable, and valid codes. However, procedures of this kind are useful only for research. They are not only time-consuming but very expensive. Ten minutes of interaction often takes an hour or more to code by a highly trained coder. Thus, a second form of assessment has been developed. This approach stimulates families to interact in situations in which their behavior is simplified and in which the behavior itself is automatically recorded. Usually family members respond to some sort of puzzle or challenge and must work dials, buttons, cards, switches, or PC paddles to interact with each other and the puzzle materials.

Preliminary Results—This important methodological shortcut has been shown to yield vivid images of family interaction that are both reliable and valid. The Card Sort Procedure (CSP) for families, is the principal example of this form of procedure. This unique procedure is now fully developed and ready for any rehabilitation center or program that is concerned about more careful assessment and support for the families of its clients. After installation,

its costs are very low, and it yields results almost instantaneously. As the manual describes, CSP permits the clinician to determine rapidly the basic problem-solving style of any family with three or more members. This problem-solving style of the family group is not related to intelligence, social class, educational level, culture, or race. Rather, it reflects the family's basic and enduring sense of its relationship to its social world.

These data about families are of critical importance to the rehabilitation practitioner for four reasons: i) The data provide the practitioner with an immediate and firm grasp of the quality of life in the family; its level of optimism, its sense of connectedness or fragmentation, and its rigidity or flexibility. ii) The data provide important clues about how to engage the family in a rehabilitation program, distinguishing those families who typically feel overwhelmed by, and retreat from, any novel social situation from those who readily engage in such situations. iii) As research results emerge, CSP will

help identify major risk factors in families. It probably will predict those families who will passively drop out of a rehabilitation program or those who will actively interfere with its success (the status of the "risk" research is summarized in the manual). iv) Finally, the problem-solving task itself is a useful way of engaging families in a rehabilitation program; the professional can provide feedback results to family members almost instantly and can help them recognize patterns of their own interaction behavior that otherwise they might not. A computerized method has been developed by which the entire CSP can be programmed for automatic data acquisition and scoring. This method offers the advantage of speed, ease of data recording, reduction and storage: high test-retest reliability and reduced staff time. In sum, CSP reflects major advances in the field of family assessment. For a modest, nonrecurring cost, a fully computerized version can be located almost anywhere. Little or no training is necessary to administer the procedure.

How Much Self-Sufficiency Does an Adolescent with a Disability Have? A New Approach to Accurate Measurement

Ann Sigafos, Ph.D.; Carl Feinstein, M.D.; Marietta Damond; David Reiss, M.D.

Purpose—A broad range of severe physical disabilities starts during or before adolescence and continues throughout adult life. These range from cerebral palsy and spina bifida, which are present at birth, to diabetes and crippling arthritis, which often appear in childhood, to epilepsy and blindness, which can occur at any age. Rehabilitation professionals are recognizing that adolescence may be the most critical phase in development for these youngsters with disabilities. In adolescence, they either forge the abilities, drives, and outlook that will propel them toward independent living for the remainder of their years, or they retreat from autonomy and independence to a conception of themselves as relatively helpless and dependent. Recognizing the central importance of this period, contemporary rehabilitation practice has emphasized programs that help the transition of these youngsters from school to work. Given this strong current emphasis on "transitioning," it is remarkable that rehabilitation professionals have virtually nowhere to turn for a systematic, reliable, and valid assessment of auton-

omous functioning in adolescence. When the professional asks about any given adolescent client, "How much initiative, independence, and autonomy does this youngster show?", he or she must fall back on crude impressions, second-hand accounts, and unreliable guesswork. Given the increasing recognition of the importance of adolescence in the rehabilitation effort, it has become imperative to develop an inexpensive, rapid, comprehensive, reliable, and valid tool for precisely assessing the level of initiative, independence, and autonomy in any teenager.

Progress—The first edition of this manual describes the Autonomous Functioning Checklist (AFC) developed in our Rehabilitation Research and Training Center. It provides the conceptual background of the AFC, compares it to other procedures, and describes how norms were established from a sample of almost 400 adolescents. In addition, it describes the reliability and validity of this instrument. Because the focus of the AFC is on the adolescent's psychosocial adjustment, and because successful

adult adjustment requires that the individual meet, at a minimum, certain critical demands of the environment, the AFC measures independent living behaviors at the level of the central requirements of adult life as indications of psychosocial adjustment to the physical and social surround. At this level, the critical requirements for living are relatively uniform. The ways in which individuals may choose to meet these requirements may not be uniform, and this individual variation in meeting environmental requirements is what the AFC is designed to assess. The AFC's measurement of autonomy as functional autonomy in relation to the requirements of the environment makes the instrument meaningfully applicable to almost any adolescent, regardless of physical, emotional, or cognitive level of functioning.

The AFC contains only information about what the adolescent actually does in daily life. This information can, in turn, be used to assess the effects of relative levels of actual (rather than estimated) competence on other adolescent characteristics, such as psychological functioning or personality. In addition, the method reflects our view that capability is necessary for performance but that autonomous functioning capability is developed and defined by repeated practice of the relevant behaviors. The AFC measures an adolescent's psychosocial adjustment independent of chronological considerations. There is no assumed relation between age group and development of initiative or display of autonomous behaviors. Therefore, the AFC measures both the diversity of the types of the adoles-

cent's experience as well as the accumulation or extent of the adolescent's practice with independent living. Further, the AFC is designed to be uniformly applicable to all adolescents, regardless of the type, degree, or even presence or absence of disability. For this reason, results obtained from the AFC are readily comparable across disability types and between disabled and non-disabled adolescents. The AFC is a 78-item parent-completed behavioral checklist for adolescents between the ages of 12 and 18. It is divided into four conceptually distinct subscales: self and family care, management, recreation, and social and vocational activity. Complete written instructions to the parent are given on the first page of the AFC; therefore, in most cases the parent or caretaker should be able to complete the AFC without assistance.

Preliminary Results—The results of its first administration to a group of adolescents indicate that its subscale scores show definite changes with age and that it has acceptable levels of validity and reliability. The AFC focuses on the behaviors that are, or are becoming, a part of the adolescent's actual behavior pattern. Thus results from diverse groups of adolescents are readily comparable. They provide a critical measure of the extent to which the adolescent is meeting daily demands of the environment in a way that is expectable for adolescents of his or her own age. They are also a measure of the extent to which the adolescent is becoming adequately prepared to function independently in adulthood.

Family-Centered Interventions for People with Chronic Physical Disabilities: The Eight-Session Multiple Family Discussion Group Program

Sandra Gonzalez; Peter Steinglass, M.D.; David Reiss, M.D.

Purpose—Through improved diagnostic and treatment technologies, medical science has increased the survival and upgraded the medical competence of many persons with severe chronic illnesses and disabilities. An obvious concern for rehabilitation specialists is the quality of the extended lifespan of those who must live with these chronic, and often severe, medical conditions. Recently, there has been a growing recognition of the critical role played by the client's family in successful rehabilitation. Even

in settings where family involvement is sought and supported by medical treatment and rehabilitation care providers, there has been a persistent, if somewhat variable, difficulty in engaging families in family-focused rehabilitation interventions. Of particular difficulty has been the establishment and maintenance of family meetings or discussion groups that deal with illness-related family dynamics and concerns.

Progress—The Multiple Family Discussion Group (MFDG) program presented in this manual is a short-term (eight weekly sessions) psychoeducationally-oriented, family-focused intervention. The groups bring together four to six entire families, including the index patient, to discuss illness-related family problems in a structured discussion format. The MFDG program offers several advantages over traditional client-focused approaches to long-term psychosocial rehabilitation. First, it addresses the needs and concerns of the group that assumes primary responsibility for day-to-day chronic illness management—the family. Second, by its very composition, it provides a forum for mutual support and sharing of coping strategies for both patients and families. Finally, it is a short-term, cost-effective intervention by which several families are treated simultaneously. The engagement of families in the MFDG program will not be a simple matter. Some of the most important patterns of family response associated with chronic illness are as follows: 1) Families are reluctant to change their ways of handling the illness; 2) Family members are often well aware of feelings of disappointment, anger, guilt, resentment, and helplessness regarding the illness, and they often experience these feelings as unacceptable in light of the patient's medical condition; 3) Family members do not, generally, talk about the illness among themselves; 4) Most families with a chronically ill member report having negative experiences with at least one part of the medical care delivery system; 5) Families coping with a chronic medical condition often feel criticized by the offer of help, particularly if the help is of a psychological nature; 6) Families coping with a chronic medical condition are often unable to find time for another illness-related activity.

There are a number of factors to consider in selecting families for participation in the MFDG program; such as patient participation, households, age, terminal illness, individuals and family psycho-

pathy and group composition. Because of its unique structure—the conjoint meeting of four to six families, including the index patients—the MFDG operates on two distinct levels: an intrafamily level and an interfamily level. On the intrafamily level, the MFDG works like a single-family intervention. On the interfamily level, the MFDG permits family members to more easily observe and understand their own attitudes and behaviors by comparing themselves with other families. The eight sessions are divided into three components, each with distinct goals, as follows: 1. The Educational Component: The first three groups of the MFDG program are focused on “educating” the families about the various ways in which family life is affected by a chronic medical condition. 2. The Individual Family Issues Component: There are two purposes of this component of the MFDG program. The first is to provide each family with the opportunity to focus on a specific family issue or problem and to receive feedback from other families and from the group leaders. Second, the work begun in the educational component is further developed. 3. The Affective Component: The final two sessions of the MFDG program are focused on the family's emotional or affective life as it influences and is influenced by the chronic stress of a serious medical condition.

Preliminary Results—It is hoped that this manual will convey an attitude at the heart of the MFDG program. This attitude, simply stated, is that it is the families themselves who are the ones best able to teach us and each other about the impact of chronic medical conditions on family life and about those attitudes and behaviors that are most helpful in coping successfully with such conditions. The most profound impact of the MFDG intervention may result simply from chronic-illness families meeting together, listening to each other, and sharing their illness-related experiences and concerns.

The Acceptance of Disability Scale

Donald C. Linkowski, Ph.D.

Purpose—Casual and clinical observers have long noted that persons with disabilities demonstrate a wide range of responses to their disabilities. Indi-

viduals who have the same or similar disabilities may say very different things about how they feel about themselves as disabled. Some say that they

hate it and that they are worthless: others may acknowledge the inconvenience but recognize that they have many more important characteristics that give them meaning and a purpose in life. The term used to describe this characteristic is "acceptance of disability." Acceptance can be low, as when the person has strong negative feelings usually accompanied by anger, denial, or depression. Acceptance is high when the person feels that the disability is only one characteristic in context with many other abilities and personal assets, and he or she exhibits pride, contentment, or happiness.

Progress—Consistent with other concepts of acceptance is the emphasis that their theory places on the subjective meaning of the disability to the impaired individual and the associated emotions and values. Wright (1960) summarizes the process of acceptance of loss as a series of value changes. The nature of these value shifts characteristic of individuals with physical disabilities who have come to accept their loss are as follows (Linkowski, 1971). 1) Enlargement of scope of values. The extent to which a person is able to see values other than those that are in direct conflict with the disability. 2) Subordination of physique. The extent to which a person is able to deemphasize aspects of physical ability and appearance that contradict his or her disabled condition. 3) Containment of disability effects. The extent to which a person is able to restrict his or her handicap to the actual physical impairment, rather than spreading it to other aspects of the functioning self. 4) Transformation from comparative to asset values. The extent to which a person does not compare himself or herself to others in terms of the areas of limitations and liabilities, but rather emphasizes his or her own assets and abilities. The Acceptance of Disability (AD) scale

was developed to understand the wide variation in behavior of persons with disabilities. Specifically, the intent is to test for relations with personal adjustment and rehabilitation outcome variables. Acceptance of disability is assumed to be an important "mediating" variable. It can assist researchers and practitioners in understanding the connection between the person's disability and self-perception and, further, in predicting independent living, educational, and vocational rehabilitation program-related outcomes.

Preliminary Results—The AD scale contains 50 items consisting of statements derived from the four aspects of the theory of acceptance of loss described above. The items in this self-report inventory were developed by the author and independently evaluated for clarity of statement and assessment of the value areas of two experts in rehabilitation counseling. Items that were judged as unclear or not central to the theory were either revised or discarded in the development of the scale. The content validity of the items was also ascertained by means of expert opinion. The AD scale was constructed to be administered directly to disabled subjects. It is an important tool for understanding and predicting the behavior of persons with disabilities, regardless of their race, sex, age, or diagnosis. The demonstrated reliability and validity of the AD scale also indicates that the measure can be adopted for clinical use in counseling and for other therapeutic purposes in rehabilitation. The manual was prepared as a preprint to provide information about this instrument as rapidly as possible and the complete instrument and instructions for administration and scoring are included in it. The AD Scale has been copyrighted by its author, Dr. Donald Linkowski.

The Issues in Disability Scale: A New Cognitive and Affective Measure of Attitudes Toward People with Physical Disabilities

E. Makas; P. Finnerty-Fried; Ann Sigafos, Ph.D.; David Reiss, M.D.

Purpose—Recent legislation leading to the mainstreaming of disabled individuals into all sectors of society has generated considerable interest in the measurement of attitudes of nondisabled people

toward people with disabilities. This interest has resulted in the development of a wide array of instruments to measure these attitudes. The aim of our research was to develop a measure that pre-

serves the valuable information gained through previous research while taking into consideration the criticisms of previous attitudinal measures.

Progress—The Issues in Disability Scale (IDS) was developed in response to this need for a new instrument to measure attitudes toward persons with disabilities. The 55-item IDS is a Likert-type scale that is based, in part, on existing measures and has been designed specifically to take into consideration criticisms of existing instrumentation. Existing instruments were examined to produce concepts to be included in the IDS item pool. Attempts were made in the selection of concepts and in the wording of items for the initial item pool, however, both to represent the multidimensionality of attitudes and to reduce the demands of social desirability. In addition, the final selection of items was based on strict reliability criteria. We also determined that initial validation of the scale would be based on behavioral as well as nonbehavioral assessment. An initial pool of 143 items was developed for possible inclusion in the IDS. These items were drawn from three main sources: i) existing attitudinal measures; ii) analysis of responses to a semantic differential pretest; and iii) consultation with disabled individuals. Approximately 75 percent of the items in the initial pool were adapted from, or suggested by, existing scales.

After the development of the initial item pool, the items were submitted to a panel of 13 individuals having expertise in one or more of the following areas: attitudes toward disabled people, attitudes toward other minority groups, and attitudinal assessment. In all, 43 items were removed from the scale, resulting in an initial IDS instrument composed of 100 items. The 100 items remaining in the item pool were arranged somewhat randomly, although consideration was given to separating items that were similar in content (e.g., setting or social distance) or target (disabled people in general or people with named disabilities). Items were placed in a seven-point Likert-type format, ranging from “strongly agree” to “strongly disagree,” with a midpoint labeled “don’t know/no opinion.” The items were checked to ensure that they reflected an approximately equal split between positively-worded and negatively-worded statements. The 100 items

were administered to two samples: i) a student sample; and ii) a “good attitudes” sample.

Preliminary Results—Analyses suggested the placement of items into six subscales on the basis of social setting. These six subscales are: i) Education: items dealing with the abilities of children and adolescents with disabilities to function in mainstreamed classroom settings (e.g., “The majority of physically disabled adolescents should attend special schools which are specifically designed to meet their needs.”); ii) Legal: items dealing with legislation applicable to disabled persons (e.g., “It is illegal in most states for people who have hereditary disabilities to be sterilized without their permission.”); iii) Intimate Social: Items dealing with close interpersonal interaction between disabled and nondisabled persons (e.g., “Most married couples do not get divorced when one of them becomes disabled.”); iv) Non-Intimate Social: items dealing with casual interpersonal contact (e.g., “One should avoid asking disabled people questions about their disabilities.”); v) Physiological Abilities: items dealing with a disabled person’s actual physical abilities (e.g., “Most blind people are self-sufficient and do not need assistance in their daily activities.”); and vi) Psychological Characteristics: items dealing with a disabled person’s emotional and psychological characteristics (e.g., “Disabled people are generally no more anxious or tense than nondisabled people.”). Theoretical analyses of the relatively high intercorrelations among some of the subscales support, rather than discredit, the multidimensionality of attitudes toward disabled people as assessed by the IDS.

Future Plans/Implications—Analyses are now underway to assess the IDS’s susceptibility to social desirability demands and its fakeability relative to the ATDP scale. Further research with the IDS is necessary, however, to determine the scale’s construct validity on the basis of other demographic variables (e.g., professional specialization, education); its concurrent validity with other attitudinal measures; and its behavioral validity in a wide array of interactions between disabled and nondisabled persons.

VII. Functional Electrical Stimulation

A. General

The Use of EMG Biofeedback and Functional Electrical Stimulation in Spinal Cord Injury

Barth A. Green, M.D.; Bernard S. Brucker, Ph.D.; Dorothea Glass, M.D.; D.R. Ayyar, M.D.;
Marilyn S. Wells, M.D.; Christy L. Holmok; Debbie Schmidt, O.T.R.

Veterans Administration Medical Center and University of Miami School of Medicine, Miami FL 33125

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This is an ongoing study comparing the relative effects of FES, EMG biofeedback and conventional therapeutic modalities (physical and occupational).

Progress—Subjects in this study are assigned to one of four groups. Subjects are required to participate a total of 16 weeks divided into 2 sequential 8-week blocks. Within each of those individual 8-week blocks, subjects are provided with only one of the three study therapy modalities. The study is designed to include four distinct groups experiencing different treatment mixtures during the two 8-week blocks. The four groups are: 1) EMG biofeedback followed by 8 weeks of FES; 2) EMG biofeedback—followed by 8 weeks of conventional therapy; 3) 8 weeks of FES—followed by 8 weeks of conventional therapy; and, 4) two consecutive 8-week blocks of conventional therapy.

The goal of this study is to examine the effects of those modalities both individually and in combination upon predefined outcome variables (i.e., dependent measures). The total number of subjects who have entered the study thus far is 34 (17 completed, 16 current, and 1 dropout).

Preliminary Results—It is not reasonable to conduct formal statistical analysis of the data at this time due to highly discrepant numbers associated with each of the four study group cells as a result of the randomization procedure. However, examination of the raw data allows the investigators to speculate with some degree of assurance upon the probable general trends. At the present time, it appears that

the four regimens employed will not show a differential effect on changing muscle strength as measured by manual muscle test. Examination of the raw data indicates that a differential outcome trend appears to be occurring regarding increases on the EMG measure for the two groups exposed to biofeedback training in contrast to the two groups not afforded that modality of therapy.

If this trend continues, and the statistical analysis supports the notion that there was a differential effect in EMG but not a differential effect in measured muscle strength, we must conclude that, while increased neural and/or muscle electrical activity is a necessary component of voluntary muscle contraction, it is not sufficient to produce an increase in measured behavioral performance among muscles that did not experience neural input for a prolonged period of time. Voluntary muscle strength, as measured by the manual muscle test, is a function of muscle condition (i.e., muscle bulk and fiber circumference) as well as neural input. The absence of neural input in the weeks and months following injury results in muscle atrophy. It seems entirely reasonable that simply increasing neural/muscle electrical activity may not be sufficient to produce the same effect that would be observed in a normal or near normal muscle.

This explanation for lack of increased muscle strength in the presence of increased voluntary motor neuron recruitment seems more appropriate for the biofeedback-conventional therapy group. Accounting for the lack of consistent increased voluntary muscle strength in the FES biofeedback group requires further considerations. When the

ongoing study was originally proposed, little was known concerning the time and work protocol necessary to produce sufficient muscle bulk and fiber types to resemble a normal upper extremity muscle. The 8 weeks of FES training were limited to 24 sessions, which we now feel, based on our experience and the experiences of others, is not enough to produce a sufficiently strong muscle. Since that time it has become evident that the FES protocol used in the ongoing study was not intensive enough to produce sufficient muscle strength.

The completed subjects in the ongoing study report that they can perform some tasks that they could not perform prior to the program and could perform others with less effort. Based on these comments, we prepared an open-ended question-

naire regarding acquired skills and general attitude toward the research program. The initial response to that survey indicates unanimous satisfaction in having participated. Additionally, every responder indicated functional improvements ranging from greater ease of performance to newly acquired abilities such as independently opening doors. Overall, the replies to the first question (i.e., Are you able to do anything now that you could not do prior to your participation?) indicate that the measurements were not as sensitive to individual gains as they should be and could result in overlooking important data. The diversity of the reports of functional gains preclude the development of a standardized test to measure improvement at the present time.

Muscle Re-education in Incomplete Quadriplegia by Electrical Stimulation

N.A. Kett, M.S., P.T.; C.J. Robinson, D.Sc., P.E.; E. Napychank, P.T.; B. Nemchausky, M.D.; J. Subbarao, M.D.
Hines Veterans Administration Hospital, Hines, IL 60141

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Electrical muscle stimulation (EMS) has been used in the re-education of lower extremity muscles in paraplegics and hemiplegics and upper extremity muscles in quadriplegics. In addition, there have been several reports of improved voluntary movement as a result of electrically stimulating lower extremity muscles in incomplete quadriplegics. While the latter example of EMS is considered an accepted adjunct to conventional physical therapy, there have been no studies verifying the effectiveness of lower extremity stimulation in muscle re-education as compared to conventional therapeutic techniques in this group.

The problem addressed by this study is whether EMS to the gluteus maximus and quadriceps femoris in incomplete quadriplegics can improve the strength of those muscles over isometric techniques alone. We also wish to determine whether EMS to those muscles can improve specific activities of daily living, such as maintaining sitting balance and transferring.

Progress—Incomplete quadriplegics (levels C5 to C8) who are a minimum of one year post-injury, will be alternately assigned to control or stimulated groups. All subjects will be screened by a ward

physician and a principal investigator. Screening will include a patient history, manual muscle test, lower extremity electromyographic assessment to rule out lower motor neuron involvement, and a CT scan to check for gross osteoporotic changes. Subjects will receive voluntary isometric exercise of the hip and knee extensors (in conjunction with electrical stimulation of these muscle groups for the stimulated group of patients) for 6 weeks, as well as training in activities of daily living. Measurements of leg spasticity (Bajd, T. and Vodovnik, L. *Pendulum testing of spasticity*. *J. Biomedical Engineering* 6:9-16, 1984) and voluntary torque of the hip and knee extensors will be made weekly, while ability to perform activities of daily living will be documented by videotaping patient performance at the beginning and end of the training program. Project tasks include: 1) obtain/calibrate equipment; 2) recruit subjects; 3) test and train subjects; 4) analyze data; and, 5) publish results.

Preliminary Results—Equipment (transducers and strain gauge indicators for measurement of hip extensor torque, 4-channel electrical stimulator) has been obtained and calibrated. Testing and training of patients are in progress. Preliminary results show

improvement in performance of activities of daily living over the course of the training program. This improvement may be related to task repetition/motor

learning rather than specifically to strength gains in the stimulated muscle groups.

Electrical Stimulation of Fast and Slow Skeletal Muscle

Richard L. Lieber, Ph.D.

Veterans Administration Medical Center, San Diego, CA 92161

Sponsor: VA Rehabilitation Research and Development Service and National Institutes of Health

Purpose—Previous studies have demonstrated that electrical stimulation effects on muscle strengthening are a function of the muscle itself. That is, muscles of different fiber type distributions and fiber architecture are differentially affected by stimulation therapy. We have, therefore, returned to a simple immobilization model in order to more clearly understand the differential response of fast and slow skeletal muscles (of different architectures) to altered activity.

Progress—These experiments (on the dog quadriceps musculature) indicate that the following three factors are most influential in determining a muscle's susceptibility to atrophy: 1) number of joints crossed; 2) muscle fiber length; and 3) percentage of slow muscle fibers. The muscle most susceptible to atrophy is the muscle which crosses only a single joint, has relatively short fibers, and a high percentage of slow fibers (e.g., the soleus or vastus intermedius muscles).

Intramuscular Electrical Activation of the Diaphragm

Michael L. Nochomovitz, M.D.

Veterans Administration Medical Center, Cleveland, OH 44106

Sponsor: VA Rehabilitation Research and Development Service (Proposal #XB186-2RA)

Purpose—This proposal is a continuation of our previous work in the development of an intramuscular diaphragm pacing system which would not entail surgical manipulation of the phrenic nerve, nor application of an electrode directly upon this structure. The application of this technique in the clinical setting would immediately open the possibility of pacing the diaphragm in a much larger group of non-quadruplegic patients for whom the present conventional technique is generally considered potentially too hazardous to attempt. The possibility of temporary pacing for patients recovering from prolonged mechanical ventilation could also be evaluated. Having demonstrated the feasibility of the approach in an acute preparation, we now propose to further develop the system with a view towards human implantation.

A unique electrode system will be required for this purpose. The prospect of noninvasive implantation with laparoscopy and the stresses placed on the electrode materials by the contracting diaphragm demand a reliable electrode design with considerable

durability. We have a prototype electrode which incorporates design features based on previous experience with intramuscular stimulation in this laboratory as well as specific work in the area of diaphragm activation. This proposal uses state-of-the-art techniques to evaluate *in vivo*, mechanical, and corrosion properties of the prototype electrode. Adaptations may conceivably be made to the prototype and to the laparoscopic technique used to implant the final electrode design. Concurrent with the development of an optimal electrode design, and the testing of mechanical and corrosive properties, we will proceed with chronic animal studies to evaluate functional viability of the electrodes and their durability in the actively contracting diaphragm. Electron microscopic and crystallographic techniques will be employed to determine causes of electrode failure.

We also incorporate a systematic physiological evaluation of the efficacy of long-term intramuscular diaphragm pacing. Serial studies will be performed during a 3 to 6 month period of chronic stimulation

to evaluate the effect on diaphragm contractility, ventilation and gas exchange, lung volumes, and cardiac function. In addition, detailed morphological and histochemical studies will be performed to examine the effects of chronic intramuscular electrical stimulation on muscle structure and fiber composition. Bacteriological studies will also be

performed along the entire length of the subcutaneous electrode tract to examine for infection in this percutaneous system. The proposal addresses the most important questions relating to eventual human implantation of the pacing system and its evaluation in a potentially wide range of clinical situations.

Electrical Stimulation of Paralyzed Muscle After Spinal Injury

C.J. Robinson, D.Sc.; N.A. Kett, M.S., P.T.; J.M. Bolam, M.S.; M.J. Chinoy, M.D.; M. Gratzner, M.D.; B.A. Nemchausky, M.D.; J.V.S. Subbarao, M.D.

Rehabilitation R&D Center and Diagnostic Radiology, Rehabilitation Medicine, and Spinal Cord Injury Services, Hines Veterans Administration Hospital, Hines, IL 60141 and Department of Physiology, Loyola University School of Medicine, Maywood, IL 60153

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Exercising muscles by stimulating them electrically has been a valuable adjunct to conventional physical therapy in rehabilitating many individuals whose limbs were immobilized from fractures or surgery or who had upper motor neuron paralysis caused by spinal cord injury or cerebrovascular injuries. Such stimulation can retard disuse atrophy, improve muscle strength, decrease time to reuse, and maintain range of motion, all of which combine to reduce the cost and time of rehabilitation.

No one has yet demonstrated a satisfactory way to predict the outcome of reconditioning programs for individuals with spinal cord injury, or for that matter, what constitutes an optimal reconditioning protocol. A lack of reliable predictive criteria can result in unrealistic hopes, or alternatively, prejudices, by the patient, therapist or physician. Any use of electrical stimulation for functional purposes (such as walking or standing) requires that the appropriate muscles first be reconditioned. Knowing what factors are important for reconditioning, and how best to achieve reconditioning, thus can serve as guidelines for selection for functional electrical orthoses. We are considering two general questions: 1) Is there an optimum way to recondition paralyzed muscle? and 2) Can we determine which patients with spinal injury have the best chance of reconditioning?

Progress—We wish to determine whether leg muscles can be reconditioned to a criterion level of performance in eight weeks or less. We thus measure a number of physical and neurological variables

before, during, and after a four-to-eight-week reconditioning period. Our experimental design reflects a compromise between the often limited length of the subject's hospitalization and what is currently known of the time needed for reconditioning. We establish baseline levels for the test variables during the first week a subject is in our program and again after four weeks of reconditioning. Finally, we monitor weekly those patients who have finished an eight-week conditioning program.

We have measured many physiological and psychological parameters in individuals with spinal cord injury before, during, and after attempting thigh muscle reconditioning. Our experiences have suggested the difficulty in quantifying "therapeutic benefits." We have monitored changes in stimulated and voluntary muscle force and fatigability, spasticity, urodynamics, and psychological status brought about by participation in our protocol. We were able to increase the force and fatigue resistance of the thigh muscles of over half of our participants. Voluntary torque increased in 7 of 16 legs in individuals with incomplete quadriplegia. Increases in quadriceps spasticity and torque were most pronounced in recently injured paraplegics. Quadriceps stimulation had mixed effects on urodynamics. More than one half the patients tested before and after attempted reconditioning showed improved urodynamics; others showed no change or a worsening. Both positive and negative changes were seen in psychological status. In dealing with potential predictive factors for reconditioning outcome, we have been investigating how such factors as time since

injury, level of injury, extent of spasticity, residual voluntary muscle force, residual muscle mass, age, psychological status, and days of reconditioning might relate to the ultimate force and fatigability achieved in a muscle undergoing reconditioning. Perhaps our most striking preliminary finding to date is that all the patients in which we saw marked changes in peak stimulated torque were within a year or two post-injury and had initial peak torques (to a 100 mA test stimulus) above 6 N-m. This finding still appears to hold even if we adjust for the days of stimulation or for the initial baseline peak. In fact, those with paraplegia of less than a year's duration often had initial baseline torques below that shown by patients whose injury was of longer duration. Legs with initial peak torques below

6 N-m showed no increase in peak torque, even if stimulated for 21 to 66 days.

Preliminary Results—Our findings point out some important factors that need to be considered when electrical stimulation of paralyzed muscle is proposed. First and foremost, early reconditioning may be essential. And, secondly, muscles may weaken past a point where it is no longer viable for them to be reconditioned.

We are presently writing up our data for publication. We would like to compare the results obtained with unresisted isotonic exercise (current work) with about 10 subjects reconditioned using Glaser's excentric/concentric exercise protocol.

Therapeutic Electrical Stimulation (TES) in the Rehabilitation of Children with Cerebral Palsy

K. Pape, M.D., F.R.C.P.(C); M. Herbert, Ph.D.; E. Wannamaker, E.Dip.P.P., M.C.P.A.;
M. Milner, Ph.D., P.Eng., C.C.E.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: *The Easter Seal Research Institute, Toronto, Canada*

Purpose—The objective of this pilot study is to assess the feasibility of long term night-time usage of therapeutic electrical stimulation (TES).

The specific goals of the project are twofold: 1) to assess if night-time application of TES is tolerated as a treatment at home by patients and their families; and, 2) to begin to assess the effectiveness of night-time TES in increasing muscle bulk, muscle strength, bone growth, decreasing muscle spasticity and improving the functional ability of the affected limb.

Progress—Five children between the ages of two and five years, with a primary diagnosis of moderate spastic hemiplegia, will participate in this study. Each child will have spastic triceps surae.

Upon entry to the study, each child will undergo a full neurodevelopmental rehabilitation assessment, a Peabody motor development assessment, a descriptive analysis of any movement pattern disorder, and description and measurement by goniometry, a

routine assessment of muscle and bone growth, and a full gait lab assessment. Application of electrical stimulation to the prime antagonists to gastrocnemius-soleus, that is, the anterior tibial and peroneal muscle groups, will be carried out at home on a daily basis. A self-reporting diary, indicating duration and frequency of treatment, and any complications, will be completed. A full evaluation will be done at the end of six months, upon completion of the study.

Preliminary Results—A pilot study is underway, with one child having received TES for 8 to 10 hours nightly for approximately four months. Hypertrophy of the stimulated muscles is apparent clinically, and marked improvements in function have been seen. Funding for this project has been received from the Easter Seal Research Institute, and initial assessments were begun in 1987.

Comparative Electromyography of Orderly and Reverse Recruitment Studied with FES

M. Solomonow, Ph.D.

Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: *LSU Department of Orthopaedics*

Purpose—This study was done to quantify the performance of electrically-stimulated muscle under orderly and reversed recruitment. The EMG recorded simultaneously from the soleus and m. gastrocnemius of the cat upon stimulation of the sciatic nerve. Force was measured at the calcaneal tendon, and the EMG from each muscle picked up with intramuscular electrodes. Two stimulation strategies were considered: the first employed orderly recruitment of motor units concurrently with rise in firing rate using the newly-developed stimulation system described before (*IEEE Trans. BME* 34:128-139, 1987), while the second utilized linear increase in pulse amplitude at several fixed repetition (firing) rates.

Progress—It was shown that during orderly recruitment the EMG from the soleus (with small motor units) registered first and, one second later, the EMG from the m. gastrocnemius (with large motor

units) indicated initiation of activity in that muscle. The records confirmed that our stimulation system, indeed, recruited units according to their size, as well as providing a smooth, two-step force increase corresponding to each muscle.

Reverse recruitment trials, in which the stimulus pulse amplitude increased linearly, demonstrated early activation of the m. gastrocnemius relative to the soleus, initial twitches and unfused force and fast-setting fatigue, all characteristic to reverse recruitment.

Preliminary Results—It was concluded that reverse recruitment required high initial firing rates to induce smooth force which, when combined with the initial activation of larger motor units, were prone to excessive fatigue in this unphysiological approach. The anticipated advantages of the orderly recruitment stimulation mode was apparent and reconfirmed.

Development of a Stimulation System for Manipulating Muscle Force With Various Firing Rate and Recruitment Control Strategies

M. Solomonow, Ph.D.

Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: *LSU Department of Orthopaedics and National Science Foundation*

Purpose—Different skeletal muscles utilize different action potential firing rate and motor units recruitment stratagems. Such strategies should be followed closely in electrical stimulation systems if fine, stable, and fatigue-free contractions are anticipated.

Progress—A stimulation system capable of manipulating muscle force in an infinite combination of strategies was designed and tested last year utilizing linearly increasing firing rate and recruitment (*IEEE*

Trans. BME 34:128-139, 1987). Expanded efforts this year resulted in further evolution of the system and now more complex stimulation strategies as described in the physiological literature for some muscles can be obtained. Specifically, the firing rate controller can provide a two-segment piece-wise linear increase, such that strategies resembling so the FDI and deltoid/biceps can be closely duplicated. A manuscript describing the evolution of the system is currently in press.

Value of Electrical Stimulation on Fertility in Male Patients with Spinal Cord Dysfunction

L. K. Lloyd, M.D.

Research and Training Center in Spinal Cord Dysfunction, University of Alabama at Birmingham, Birmingham, AL 35294

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—Infertility is a major problem among males with spinal cord injury (SCI). In fact, infertility rates range from 99 percent for neurologically complete quadriplegics to 90 percent for neurologically incomplete paraplegics. This study seeks to: 1) determine optimal conditions for producing seminal emission via electrical stimulation of the pelvic sympathetic nerves; 2) compare electrical stimulation with strong vibratory stimulation of the genitalia in eliciting seminal emission in male SCI patients; 3) determine if repeated stimulation improves semen quality (sperm count, motility, and morphology); 4) determine if intermittent testicular cooling improves semen quality; 5) relate success or failure of seminal emission production to neuro-level and the extent of spinal lesion, urodynamic assessment of lower urinary tract function, and incidence of recurrent urinary tract infection; and, 6) artificially inseminate a male SCI's partner who had been unable to be impregnated since the patient's injury.

Progress—Male SCI patients voluntarily participating in the study are randomly assigned to electrical stimulation or vibratory stimulation groups. Seminal emissions are acquired and the sperm examined for viability. Patients failing to produce viable sperm in either group undergo stimulation with testicular cooling. Viability of sperm produced is determined. Success/failure of seminal emission production is assessed statistically. Female partners of patients with satisfactory sperm production by either mo-

dality will be evaluated physically and, if in good health, artificially inseminated.

Preliminary Results—As of November 10, 1986, 14 patients had been entered into the study. Of these, 11 were entered into the electrical stimulation group, one of whom was subsequently switched to the vibratory stimulation group. Semen was obtained from all 10 remaining patients in the electrical stimulation group. Most had adequate sperm counts but none had more than 15 percent motility (viz. sperm viability). Therefore, no female partners were artificially inseminated. One patient in this group was interested only in sperm-banking for future use.

Instructions for use of the vibrator are distributed to all study patients when they enroll in the vibratory stimulation group. Of the four patients in the vibratory stimulation group (one of whom, as indicated, crossed over from the electrical stimulation group), two have completed treatment. Semen was obtained from one of these patients; however, the second patient was not able to ejaculate. In an attempt to improve semen quality, three patients have been entered into the intermittent testicular cooling trial. The first patient's compliance was poor and no improvement was observed in semen quality. The remaining two patients have not yet completed the trial.

Future Plans—Data collection will continue until 1990. The last year of the project will include data analysis.

A Multichannel Biotelemetry System

Michael W. Keith, M.D.; P. Hunter Peckham, Ph.D.; John Schild, B.S.

Case Western Reserve University Rehabilitation Engineering Program and Electronics Design Center; Veterans Administration Medical Center, Cleveland, OH 44106; Metropolitan General/Highland View Hospital, Cleveland, OH 44109

Sponsor: *National Institutes of Health*

Purpose—The objective of this research is to develop an implantable telemetry device for use in acquiring

command control and feedback information in neuroprosthetic applications.

Progress—An eight-channel telemeter has been designed and fabricated, using thick film circuitry and semi-custom CMOS technology. The system architecture is organized into five distinct modules, front-end analog processing, signal quantization, system control circuitry, power supply, and data communications. The modularity allows the system to be configured to acquire a variety of input signals with a minimum amount of engineering design. Irrespective of the application, only the analog processing circuitry, provided for each channel, needs to be reconfigured to accommodate the amplitude and frequency characteristics of the individual input signals; the balance of the telemeter circuitry remains unchanged.

A large reduction in circuit complexity and increased communications accuracy is obtained through discrete representations of the multiple channels of input information. This is most efficiently obtained through an analog to digital (A/D) conversion of the input signal. To facilitate hybridization and increase circuit accuracy and reliability, an eight-bit commercial converter was incorporated into the design. Although possibly providing inadequate resolution for the more sophisticated biosignal processing algorithms, an eight-bit device was felt to be sufficient for initial system implementation. The conversion rate of the A/D dictates the overall system bandwidth, which for the device selected, is limited to 24KHz. Individual channel sampling rate is then a function of the number of input channels acquired. For example, a four-channel system would be sampled at 6.0KHz per channel, an eight-channel system at 3.0KHz per channel.

The converted data is latched and time multiplexed in a serial format onto a pulse code modulated (PCM) subcarrier. This processing, along with the supervisory control for the A/D, is handled by the system control circuitry. This circuitry is implemented onto a single CMOS semi-custom integrated circuit. This provides a significant decrease in power, required substrate area and circuit complexity, and as a result, system reliability is greatly improved.

The remaining two modules, power supply and data communications, may be essentially combined into one. System power is derived from transcutaneous inductively coupled radio frequency (RF) energy. Through a technique of reflectance modu-

lation, we utilize this inductive link to telemeter out the acquired data. As the primary (transmitting) coil is brought within the vicinity of the secondary (implant receiving) coil, electromagnetic energy is drawn from its radiated field. A loading effect proportional to the level of coupling between two coils manifests itself as a net change in the voltage across primary windings. By allowing the PCM data stream to modulate the amount of loading on the primary coil, data may be passed back over the inductively coupled RF power link.

Preliminary Results—A four-channel version of the implantable telemetry system, configured to acquire electromyographic signals, has been realized in thick film hybrid circuitry. To facilitate communications and prototype development, the sampling rate of the ADC was reduced to 11KHz. This corresponds to a 2.75KHz per channel sampling rate. The front-end analog circuitry provides differential amplification and bandpass filtering. Signal gain is fixed to 2000, providing a 10 μ V per bit sensitivity, with low and high frequency cutoff points set at 4.8Hz and 1.3KHz respectively. The entire system consumes slightly less than 80mW of power with 85 percent of this being required by the analog circuitry. The system is currently undergoing laboratory evaluation and initial results indicate an overall error of less than ± 1 LSB. The hybrid substrate measures 1.0 x 1.0 inches, compatible with the current version of our implantable stimulator.

Future Plans/Implications—The RF powering and data recovery circuitry is currently undergoing redesign to optimize efficiency and coil displacement tolerance. We will package this completed circuitry in the identical titanium capsule which is used for packaging our implantable stimulator. This device will then undergo a series of *in vitro* and *in vivo* testing using a similar model as used to evaluate our implanted stimulator.

Publications Resulting from This Research

- A Low-Power Multichannel Biotelemeter.** Schild JH, Roscoe DD, Keith MW, *Proceedings of the 7th Annual Conference of the IEEE/Engineering in Medicine and Biology Society*, September 27-30, 1985, Chicago, IL, in *Frontiers of Engineering and Computing in Health Care*, 2:1205-1210, 1985.

Mechanism of Torque Generation: Implications for Stimulation Therapy

Richard L. Lieber, Ph.D.

Veterans Administration Medical Center, San Diego, CA 92161

Sponsor: *National Institutes of Health*

Purpose—Based on the hypothesis that muscle is strengthened in proportion to the amount of stress it experiences, our goal was to understand the interrelationship between muscle force generation and joint kinematics in production of torque. We hypothesized that skeletal muscle should be stimulated at the joint angle which produces maximum muscle force. This angle may or may not coincide with the optimal joint angle (i.e., the angle at which maximum torque generation occurs).

Preliminary Results—In the frog hindlimb, where sarcomere length, joint kinematics and joint torque were directly measured ($n = 10$), optimal joint angle occurred at 140 degrees of knee flexion, while maximum muscle force was generated at 160 degrees of flexion. Thus, for the frog system, increased muscle strengthening would presumably be obtained by activating the muscle at 160 degrees of flexion.

Future Plans—Analagous studies are planned for rabbit and human models.

The Use of EMG as Force Feedback in Closed-Loop Electrical Stimulation System

M. Solomonow, Ph.D.

Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: *National Science Foundation*

Purpose—Force feedback is necessary if regulation of a stimulated muscle force output is anticipated. Since implantation of force sensors requires traumatization of the tendon, the EMG was considered, tested, and evaluated as a parameter representing force in a closed loop paradigm (*IEEE Trans. BME*, 33:735-745, 1986).

Progress—The EMG was found to follow the force rather faithfully as long as fatigue did not set in the muscle. To prevent muscle abuse and possible damage due to prolonged and frequent fatigue, a parallel feedback/fatigue detector was implemented. The role of the circuit was to function as a "fatigue fuse," terminating contractions if excessive fatigue was detected.

EMG-Force Models in Muscles With Various Firing Rate and Recruitment Strategies

M. Solomonow, Ph.D.

Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: *National Science Foundation*

Purpose—The EMG-Force relationships were a controversial and unsolved problem for many years, having been reported as linear by many investigators, and as non-linear by many others. Recent data reported by scientists in the NeuroMuscular Research Center at Boston University and elsewhere pointed out that the different firing rate and recruitment strategies of different muscles may be the source of the controversy.

Progress—With the aid of the new stimulation system we developed (described elsewhere in this report), the effect of various control strategies on the EMG-Force relationships was investigated. It was shown that strategies employing recruitment of all the motor units of the muscle to generate the initial 50 percent of the maximal force, in conjunction with pure firing rate increase to generate the final 50 percent of the force, yields a linear EMG-Force

model. Progressive increase in the force proportion by recruitment over 50 percent results in a predictable progressive increase in nonlinearity of the relationships.

Complete models were developed for various control stratagems as well as for fast and slow twitch muscles and described in several articles now in press.

Control of Joint Motion With Synergistic Stimulation of Its Agonist/Antagonist Muscles

M. Solomonow, Ph.D.

Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: National Science Foundation

Purpose—Joint motion requires complex and simultaneous activation levels from the agonist and antagonist muscles in order to accomplish the intended task while subject to various internal and external disturbances (*Am J Phys Med* 65:223-244, 1986). This project initiated trials using antagonistic stim-

ulation of the muscle groups, crossing the joint with various levels of weighted motor unit recruitment in the agonist and antagonist, to reaffirm our data collected from the elbow joint of humans. The objective was to improve the external control of a joint with regard to various loading conditions.

Closed-Loop Control of Functional Neuromuscular Stimulation Using Implantable Force Sensors

J.A. Hoffer, Ph.D.

Department of Clinical Neurosciences, The University of Calgary, Faculty of Medicine, Calgary, Alberta T2N 4N1, Canada

Sponsor: Paralyzed Veterans of America, Spinal Cord Research Foundation (Proposal NBR-623)

Purpose—The goal of this work will be to develop and evaluate, in an animal model, an implantable force sensor suitable for the feedback control of functional neuromuscular stimulation (FNS) of paralyzed muscles. The FNS approach is being used experimentally in selected patients for the restoration of grasp or gait and posture. However, in the present applications, the forces generated with FNS are very sensitive to changes in limb position, external load, and muscle fatigue, forcing the user to rely heavily on visual feedback in order to control the desired function. To provide closed-loop control of FNS, it is necessary to use suitable position and force sensors. In this research, implanted nerve cuff electrodes will be used to record the electrical signals naturally generated by touch receptors in the skin. In pilot animal experiments, we have shown that the signal recorded by nerve cuff electrodes can be roughly proportional to the force applied on the

skin. In the first year of this research, the detailed properties of the recorded signal will be evaluated for a range of force conditions that will simulate the natural manipulative or gait situations likely to be experienced by human users.

Future Plans—In following years, implanted nerve cuff electrodes will be used to provide a feedback signal suitable for controlling the force generated with FNS of paralyzed muscles. Experiments will be done first in animals under anesthesia and later in intact animals, where the forces produced with FNS can be directly compared to the natural forces produced during walking and postural adjustments. Once the effectiveness and limitations of this experimental approach are determined, this technique may be ready for immediate implementation in human users.

Neuromuscular Stimulator with EMG Pick-Up Circuitry

Marco Knaflitz, M.S. and Roberto Merletti, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Politecnico di Torino, Torino, Italy*

Progress—In 1985, a research project was undertaken to develop optimized strategies for electrical muscle stimulation using a prototype instrument that could simultaneously stimulate and record the myoelectric responses from the surface of a muscle. This stimulation technique has a variety of applications in our laboratory's study of neuromuscular control strategies and clinical assessment of neuromuscular diseases.

Based on the success of this prototype instrument, a new neuromuscular stimulator with EMG pick-up circuitry was designed and fabricated as a joint project with researchers at the Department of Electronics, Politecnico di Torino, Italy, during the summer of 1986. This fall, the completed stimulator has been undergoing extensive evaluation in the Center's Motor Unit Laboratory.

The new instrument offers improved performance

and overcomes several technical limitations of the prototype. It contains a neuromuscular stimulator, which gives monopolar stimulation pulses at prescribed frequency and width, and specialized myoelectric signal detection circuitry, which rejects the undesirable electrical artifacts that accompany each stimulation pulse. The myoelectric signals resulting from each stimulation pulse are detected using a four-bar surface electrode technique. One of the most important design considerations of the new instrument is insurance of patient safety. The circuitry was carefully designed to isolate the electrodes and patient from potentially harmful power-line voltages.

The new instrument will be the foundation for a series of research projects aimed at investigating stimulated myoelectric activity.

Properties and Control of Stimulated Muscles

William K. Durfee, Ph.D.

Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: *Whitaker Foundation*

Purpose—The objective of this research program is to develop controllers for electrically-stimulated muscles, using mathematical simulations and experimental animal models. Given the embryonic stage of neural prostheses (devices which use electrical stimulation to return function to paralyzed muscles), simulation and animal models are crucial research steps which must be taken before neural prostheses become a clinical reality.

Progress—In our experiments, we are studying the stochastic nature of the response of a single isolated cat muscle to electrical stimulation and attempting to develop mathematical models to explain the

experimental data, with the hopes of determining the model complexity required to develop neural prosthetic controllers. Using these models, we will explore suitable algorithms for neural prosthetic controllers. Given that the muscle is a nonlinear actuator, whose properties cannot be perfectly modeled, appropriate nonlinear control techniques will be tested both by computer simulation and in animal models.

Publications Resulting from This Research

Recruiting Isometric Muscle Force by Electrical Stimulation.
Durfee WK, MacLean KE, *Proceedings of the IEEE-EMBS Ninth Annual Conference*, Boston, MA, 1987.

B. Upper Limb Applications

Portable Functional Neuromuscular Systems for Upper Extremity Control

P. Hunter Peckham, Ph.D. and James R. Buckett

Case Western Reserve University Rehabilitation Engineering Program; Veterans Administration Medical Center, Cleveland, OH 44106; Metropolitan General/Highland View Hospital, Cleveland, OH 44109

Sponsor: VA Rehabilitation Research and Development Service and National Institute on Disability and Rehabilitation Research

Purpose—The purpose of this project is to develop portable functional neuromuscular stimulation (FNS) systems for restoration of upper extremity function in high level spinal cord injured subjects.

Progress—Progress in the past year has been made in the fabrication of portable FNS systems, enhancement of the portable system software and enhancement of the portable system programming system software. The portable FNS system consists of several elements. They include: the command sensor, the controller package, and the programming system. The command sensor is a miniature proportional two-axis joystick which measures shoulder position relative to the sternum. One axis of shoulder position continuously controls hand prehension/release while the orthogonal axis controls system logic.

The controller package is based on two CMOS microprocessors (CDP6805E3) and contains a microprocessor-based input processor, a microprocessor-based stimulus parameter modulator, and the stimulation interface. The input processor is responsible for the processing of the transduced input commands. This can range from simple gain and filtering to realization of nonlinear input/output transfer functions. These processed input commands are used as inputs to the supervisory control algorithm which provides the user with a quick and convenient means of controlling the grasp function realized by the FNS system. The control scheme utilized in the neural prosthetic hand system provides the user with the mechanisms to turn the stimulations on and off, to select one of several predefined hand-grasp patterns, to control the grasp pattern in a continuous proportional manner, and to lock the proportional command at any desired level. The supervisory control algorithm is responsible for control of the machine operating state and state transition of the FNS system. It is also re-

sponsible for the feedback of the machine state to the user.

The output(s) of the control algorithm are used as the input stimulus parameter modulator. The modulator coordinates and regulates multiple channels of stimulus waveform parameters. The output of the stimulus parameter modulator is used by the stimulation interface to produce graded coordinated muscular movement and/or a perceived stimulus for sensory feedback. The stimulus outputs can be either external, for stimulation through chronically indwelling percutaneous electrodes, or generated by a totally implantable stimulator. In the case of a percutaneous output, the stimulation interface is a sixteen-channel constant current capacitively coupled biphasic stimulator. Alternatively, up to four, eight-channel implantable stimulators can be used. The interface in this case can be up to four radio frequency (RF) transmitters. Pulse width, interpulse interval, and current amplitude for each output channel, as well as various input controller parameters, are predetermined on a laboratory-based stimulation system. An IBM PC is then used to program the various operating characteristics into the portable FNS system.

Future Plans/Implications—Our plans are to continue the evaluation of this system in human subjects and to transfer this technology for fabrication outside of our Center.

Publications/Patent Resulting from This Research

A Flexible, Portable Functional Neuromuscular Stimulation Neuroprosthetic System. Buckett JR, Peckham PH, Thrope GB, Braswell SD, Keith MW, *IEEE Transactions in Biomedical Engineering*, accepted for publication, 1987.

A Man/Machine Interface for Control of an Upper Extremity Functional Neuromuscular Stimulation System. Buckett JR, Johnson MW, Thrope GB, Ignagni AR, Peckham PH, *Proceedings of the Tenth Annual Conference on Rehabilitation Technology (RESNA)*, 7:660-662, San Jose, CA, June 1987.

A Modular Approach to a FNS System: The Portable Control Hardware. Buckett JR, Peckham PH, Smith B, Thrope GB, Keith MW, *IEEE/Engineering in Medicine and Biology*

Society Meeting, Boston, MA, November 1987.
A patent entitled *Functional Neuromuscular Stimulation System* was filed for in the past year (Serial No. 843,159).

Quantitative Assessment of a Functional Neuromuscular Stimulation Motor Prosthesis for Restoration of Grasp in the Quadriplegic Hand

P. Hunter Peckham, Ph.D.; Michael W. Keith, M.D.; Geoffrey B. Thrope, M.S.; Kathy C. Stroh, OTR/L
Case Western Reserve University Rehabilitation Engineering Program; Veterans Administration Medical Center, Cleveland, OH 44106; Metropolitan General/Highland View Hospital, Cleveland, OH 44109

Sponsor: VA Rehabilitation Research and Development Service and National Institute on Disability and Rehabilitation Research

Purpose—The purpose of this project is to enhance the functional capability of the paralyzed hand in the quadriplegic, through the use of functional neuromuscular stimulation (FNS) and surgery.

Progress—Subjects are provided with a neural prosthetic hand system which consists of a command control device, portable patient-based stimulation unit, stimulation interface (percutaneous intramuscular electrodes or antennae for implantable stimulation unit), and cabling to connect the stimulation unit to the interface. The control scheme is typically a proportional control source (usually the transduction of the motion of the opposite shoulder from the stimulated hand).

The FNS hand system is applied during dressing, enabling the subject to use his hand throughout the day. The system provides both lateral prehension/release and a palmar prehension/release. The grasping mode is selected by a scanning technique, activated by depressing a switch mounted to the chest. The system can be placed in a locked mode which applies a constant non-varying stimulus to the hand muscles regardless of the command controller activity.

Tests are under development to provide a quantitative measure of the effectiveness, consistency, and ability of the user to operate the grasp and release function of the FNS hand system during activities of daily living (ADL). The areas of assessment consist of a physiological evaluation and a functional evaluation. The physiological evaluation involves sensory testing, passive range of hand motion for shoulder, arm, and hand, active range of motion using FNS, and motor mapping to determine the extent of upper and lower motor neuron lesions by surface stimulation and EMG recordings.

The functional evaluation concentrates on the ability of the user to grasp and release singular items of varying geometries and masses and a coordinated activity determining the ability of the user to manipulate items which he uses during ADL.

Results—The FNS system has been fitted to 26 subjects with spinal cord injury at the C5 or C6 level. Five of these subjects additionally have had surgical procedures such as arthrodeses, tenodeses, and tendon transfers of paralyzed but excitable muscles. One subject has had a multichannel receiver-stimulator surgically implanted. Subjects have been in the program for as long as nine years and averaging 3.6 years.

The results are that:

1) FNS enables C5 and C6 level quadriplegic individuals to control lateral (key-grip) and palmar prehension and release. The individuals use their hand to perform independently functional tasks that they cannot perform without the use of the hand system. The ability to acquire and use a common item such as a fork or glass without the aid of adaptive equipment greatly enhances a subject's level of independence.

2) C5 and C6 level quadriplegics can perform functions independently (e.g., eating, drinking, grooming, writing), using the FNS hand system that they cannot accomplish otherwise, unless assisted by an attendant. Objects need not be modified, nor are special adaptations needed for acquiring the objects.

3) Performing transitional tasks such as eating with a fork, drinking from a glass, and reacquiring the fork are achieved.

4) Using the hand system allows increased unilateral activity, freeing the opposite arm for stabi-

lizing the person's balance during functional activity.

5) C6 level quadriplegics with tenodesis pinch require the FNS hand system when the task requires any greater than minimal pinch strength.

6) Most users have weak proximal musculature and poor balance which degrades functional performance.

7) Comparing performance with and without the system, C5 subjects improve in every task. C6 subjects may perform better in some tasks with FNS, and worse in other tasks. However, the quality of performing the task is always enhanced with FNS.

8) Factors that hamper the effective usage of the system, such as joint stability and lower motor neuron lesions, may be improved by surgical procedures used in conjunction with FNS.

9) Usage of the hand system has required introduction of new training modalities into the rehabilitation program.

10) FNS techniques for hand control have been transferred and are presently being utilized and evaluated with patients in rehabilitation centers in Edmonton, Alberta, and Toronto, Ontario.

Future Plans/Implications—The implications of these results indicate that the technique of using an intramuscular electrode FNS system does provide the user with higher quality function. The use of an implantable stimulator has eliminated maintenance

of the percutaneous interface. However, the process regarding reliability and ease of maintenance of these systems must be enhanced as a research tool in order to demonstrate the long-term effectiveness of the system. New training and conditioning programs are required to achieve optimal performance. Surgical intervention such as arthrodesis, tendon transfer, and tenodesis coupled with the use of our FNS techniques can overcome some physiological limitations.

We plan to extend our program to new subjects in our program and those of our collaborators in Edmonton and Toronto. We also plan to further evaluate the surgical techniques that we have introduced, and to further extend our quantification measures and training procedures.

Publications Resulting from This Research

Functional Electrical Stimulation: Current Status and Future Prospects of Applications to the Neuromuscular System in Spinal Cord Injury. Peckham PH, *Paraplegia* (Silver Jubilee Issue), 25(3):274-288, 1987.

Functional Activation of the Paralyzed Extremities. Peckham PH, *Encyclopedia of Neuroscience*, 1987 (in press).

Functional Electrical Stimulation. Peckham PH, in *Encyclopedia of Medical Devices and Instrumentation*. Accepted for publication, John Wiley & Sons, Inc., 1987.

Restoration of Functional Control in the Tetraplegic Upper Extremity by Electrical Stimulation. Peckham PH, Keith MW, Freehafer AA. Accepted for publication in *Journal of Bone and Joint Surgery*, 1987.

Feasibility Assessment of a FNS Hand Orthosis for Quadriplegics

J. Bugaresti, M.D., F.R.C.P. (C); S. Naumann, Ph.D., P.Eng.; M. Herbert, Ph.D.; M. Verrier, M.H.Sc.; S. Sharma, M.D., F.R.C.P.(C), M.B.B.S., M.S. (Ortho); C. Brenchley, B.Sc., O.T.
Hugh MacMillan Medical Centre, Toronto, Ontario M4G 1R8

Sponsor: Department of Rehabilitation Medicine, University of Toronto and The Canadian Paraplegic Association

Purpose—The objective of this study is to determine, in conjunction with Dr. H. Peckham and Dr. M. Keith, Highland View Hospital and Case Western Reserve University, Cleveland, Ohio, the feasibility of implementing a clinical program to provide hand prehension abilities to quadriplegics through functional neuromuscular stimulation (FNS).

A pilot study will explore the feasibility of implementing a clinical program in FNS by: 1) observing the prehension ability and activities of daily living (ADL) skills in three C5 quadriplegics using an FNS orthosis; 2) observing the compliance of three C5 quadriplegic individuals to use of an FNS orthosis

to provide prehension ability; 3) observing the amount of clinical and technological support required to maintain a functional FNS orthosis in three C5 quadriplegic individuals; and, 4) documenting the patients' and families' reaction to the FNS orthosis.

This study will attempt to define factors which should be addressed in a prehension ability assessment for individuals using the FNS orthosis. In addition, existing technology will be used to develop a system to track upper extremity movements during performance of specific functional tasks.

Progress—Three individuals with C5 quadriplegia

will be given implanted stimulating electrode systems and will be trained to use the FNS orthosis. Prehension ability and ADL skills of the orthotic users will be observed at regular intervals for two years following electrode implantation. Compliance to use the FNS orthosis, as measured by data acquisition devices, and acceptance of the orthosis, determined through patient and family interview, will be addressed. Clinical and technological support required to maintain a functional orthosis will be measured.

New evaluations designed to distinguish between unilateral and bilateral prehension abilities in quadriplegia are being developed. The new proposed evaluations, and existing hand function tests are to be administered to C5 quadriplegic patients using the FNS orthosis. Modifications to the tests will be made, as required, to create evaluations capable of measuring the prehension abilities and ADL skills of C5 quadriplegic patients using an FNS orthosis.

Kinematic studies will be conducted to track functional upper extremity movements requiring prehension abilities. Prehension abilities, compliance to use of the FNS orthosis, and clinical and technological support required will be used to determine the feasibility of establishing a clinical FNS program. Results of the kinematic studies may indicate new learning strategies for future orthosis users. Finally, the evaluations created to measure

prehension abilities and skill in ADL in the C5 quadriplegic will be of value for future related clinical trials.

Preliminary Results—One subject was implanted in early December, 1986, with a total of 21 percutaneous intramuscular electrodes. The number of electrodes has since been reduced to 12: six to provide prehension, and six to provide release. Threshold and impedance measurements have been undertaken on a regular basis to confirm electrode integrity. A transducer to measure the force exerted by the thumb during stimulation to effect prehension was designed and constructed. These measurements will enable us to profile the influence of an exercise program on muscle strength and to record actual pinch strength.

Future Plans/Implications—A method for determining upper extremity movements during targeting tasks is reaching completion. Experiments to compare extremity trajectories of the first subject in this study with a group of normal subjects performing the same tasks was begun in early 1987.

Concurrent with the technological tasks described above that reflect the efforts of personnel at the Hugh MacMillan Medical Centre, the functional assessment and other related research projects are underway at Lyndhurst Hospital.

Miniature Sensor for Two-Degree-of-Freedom Position Transduction

P. Hunter Peckham, Ph.D. and James R. Buckett

Case Western Reserve University Rehabilitation Engineering Program; Veterans Administration Medical Center, Cleveland, OH 44106; Metropolitan General/Highland View Hospital, Cleveland, OH 44109

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The purpose of this project is to develop a two-degree-of-freedom position transducer for use as a command source in upper extremity assistive systems for individuals with high-level spinal cord injury. Command signals are generated by the user from some remaining voluntary function.

Progress—In the case of spinal cord injury, individuals with injury levels as high as C4 retain some degree of shoulder motion. The concept of shoulder position as proportional command source has been studied recently in detail as a control source for

neural prosthetic hand systems. A miniature two-orthogonal axis proportional position transducer measures the scapular movement of the shoulder. The shoulder position transducer body is mounted to a small plate. The plate slips into a small leather pad which is attached to the user's chest with double-sided adhesive tape. A position sensing arm extends from the transducer's body and a mounting pad at its end is secured to the shoulder with tape. The outputs of the transducer are proportional to shoulder elevation/depression and protraction/retraction, relative to the sternum.

The transducer is based on linear Hall Effect devices. A permanent magnet is contained within the ball member of a ball and joint socket. Four Hall Effect sensors are arranged in differential pairs and contained in the socket member perpendicular to the magnet with the ball in the center of its range of motion. When the ball and magnet assembly are in the center position, equal amounts of magnetic flux density couple into the differentially configured Hall Effect sensors. The net output of the sensors is zero. As the sensing arm of the transducer is moved away from the center position, more magnetic flux density is coupled into one sensor and less into the second, resulting in a net output in the direction of movement. The second differentially connected pair of sensors, which is at a right angle to the first pair, allows the position of the sensing arm to be related to two proportional outputs. This relationship is approximately linear over the 20 degrees of movement in any direction from the center point. The interface circuitry provides a proportional bipolar voltage output. Current consumption of the transducer and interface circuitry for a two-channel five-volt bipolar output is approximately seven milliamperes. Pulse powering the device during analog to digital conversion allows a

magnitude of order decrease in the current consumption.

The fabrication effort and cost to produce the shoulder position transducer has been greatly reduced in comparison to our previous coil style transducer through the use of commercially available Hall Effect sensors. Our earlier transducer utilized small coils which were fabricated one at a time by hand. The sensors are mounted on a small circuit board which fixes their position. Also mounted to the circuit board is a small multipin connector for the cable attachment. This sensor/connector assembly is contained within the transducer body (the socket member), which is molded in acrylic.

Future Plans/Implications—Our plan is to incorporate this control device in our upper extremity motor prostheses and evaluate its function as the command control source in control of grasp/release in the quadriplegic user.

Publications Resulting from This Research

A Multichannel Portable Functional Electrical Stimulation System. Buckett JR, Braswell SD, Peckham PH, Smith B, Thrope GB. *Proceedings of the Ninth Annual Conference on Rehabilitation Technology (RESNA)*, 6:432-434, Minneapolis, MN, June 1986.

Sensory Augmentation for FNS Upper Extremity Prostheses

Ronald R. Riso, Ph.D.; Michael W. Keith, M.D.; Anthony Ignagni, B.S.

Case Western Reserve University Rehabilitation Engineering Program; Veterans Administration Medical Center, Cleveland, OH 44106; Metropolitan General/Highland View Hospital, Cleveland, OH 44109

Sponsor: *National Institute on Disability and Rehabilitation Research; National Institutes of Health*

Purpose—The purpose of this project is to develop substitute and augmentative sensory feedback to enhance the utility of functional neuromuscular stimulation (FNS) upper extremity prostheses.

Progress—A sensory feedback system based on electrocutaneous communication techniques has been developed that provides information about prehensile force, the output of the FNS system user's command transducer and stimulator status. Stimulation of the skin to evoke the electro-tactile sensations is achieved using a five-element array of subdermally placed indwelling coiled wire electrodes. Stimulus coding parameters and waveform characteristics have been optimized for comfort,

stability, and discriminability of the feedback signals. This feedback system is presently being implemented in portable FNS systems using percutaneous leads, but will ultimately utilize an implanted stimulator to minimize external hardware and enhance system reliability and cosmetic acceptability.

The output of the user's command transducer is displayed by a spatial position code, while feedback of grasp force is simultaneously displayed by varying the pulse repetition rate of whichever electrode is active, using five or six discrete frequencies.

Machine-state information consists of a set of electrocutaneous messages that assist the user with: 1) selection of the grasp mode (lateral versus palmar); 2) specification of the position of the shoulder

that corresponds to the start point of command range; and, 3) realignment of the shoulder prior to regaining active hand control after the system has been put into a "lock grasp" state. Lock grasp refers to the condition during which the user can maintain the muscle stimulation parameters at any arbitrary level and disengage the shoulder position controller.

Preliminary Results—A simplified sensory feedback system has been designed and implemented in one C6 individual who received an implanted FNS system. This wholly implanted electrocutaneous communication system uses a display that consists of a single subdermal electrode, so that it can be driven using just one of the eight independent output channels of the implantable stimulator. A platinum-iridium disk electrode (identical to the epimyseal type used for stimulation of the muscles) was surgically attached to the underside of the skin of the user's chest to provide the electrocutaneous interface. This feedback system provides a five-level frequency encoded signal that tracks the command controller output and provides machine-state information similar to that described for the multi-electrode sensory system. The user has had approximately one year's experience with the implanted system and states that he is pleased with the comfort of the cutaneous sensations and the utility of the

information provided. He has also expressed satisfaction with the privacy inherent in the cutaneous communication scheme in comparison to the percutaneous FNS system which he used previously that provided machine-state information via auditory tones.

Future Plans/Implications—Future work will concentrate on performing functional evaluations of the sensory feedback systems in selected quadriplegic individuals.

Publications Resulting from This Research

- Sensory Feedback of Machine-State and Shoulder Position Command Information for Use with FNS Hand Orthoses.** Riso RR, Ignagni AR, *Proceedings of the 9th Annual Conference on Rehabilitation Technology*, 6:325-327, Minneapolis, MN, 1986.
- Transition Accentuation Improves FM Sensory Feedback Codes.** Riso RR, Ignagni AR, *Proceedings of the 39th ACEMB*, Baltimore, MD, 1986.
- Sensory Augmentation for Enhanced Control of FNS Systems.** Riso RR, *Ergonomics in Rehabilitation*, A. Mital (Ed.), Taylor Francis, London, England, 1987 (in press).
- Sensory Augmentation for Enhanced Control of FNS Grasp Restoration Systems.** Riso RR, Ignagni AR, Keith MW, *Proceedings of the 9th International Symposium on External Control of Human Extremities*, August 30-Sept. 4, Dubrovnik, Yugoslavia, 1987 (in press).
- Sensory Feedback Using Electrical Stimulation.** Szeto AYJ, Riso RR, *Rehabilitation Engineering*, R.V. Smith and J.H. Leslie (Eds.), CRC Press, Boca Raton, FL, 1987 (in press).

Artificial Sensory Transducer

Michael R. Neuman

Case Western Reserve University, Cleveland, OH 44106

Sponsor: *National Institutes of Health*

Purpose—The principal goals of this research project are to develop artificial sensory transducer systems and to evaluate them in conjunction with a paralyzed hand under functional neuromuscular stimulation (FNS) control. In addition to developing force and position transducers, the contractor will investigate the feasibility of measuring shear forces on the grasping surfaces of finger tips as an indication of

incipient slippage. Although the development of FNS systems is not a part of this contract, the contractor will be encouraged to work closely with other investigators in the Neural Prosthesis Program to integrate the transducers into closed loop feedback control systems for restoration of grasp in quadriplegic individuals.

Implantable Systems for Stimulation of Skeletal Muscle

P. Hunter Peckham

Case Western Reserve University, Cleveland, OH 44106

Sponsor: National Institutes of Health

Purpose—The objective of this project is to develop an implantable stimulator system for electrical excitation of paralyzed skeletal muscle. This system will be utilized by high level (C5 and C6) spinal cord injury patients to provide controlled grasp and release in the hand. In this application, functional neuromuscular stimulation has previously been demonstrated to be effective by employing chronically indwelling percutaneous electrodes. Through the use of the implantable system, we expect that the ease of use of the system and its reliability will be improved, leading to greater independence for the quadriplegic patient.

The objective of development of the implantable system will be met by: 1) development of circuitry using a high density of integration to perform the stimulation function; 2) development of techniques for encapsulation of the stimulator in a hermetic package suitable for extended periods of implanta-

tion (greater than 5 years); 3) development of stimulation electrodes and lead wire interconnections which are suitable for use with the implantable stimulator; 4) development of a programmable control transmitter which is worn externally by the subject and regulates the output of the implant stimulator in response to the control signals generated by the subject; 5) evaluation of the entire system and individual subsystems (eg., electrodes, packaging) *in vitro* and *in vivo*; and, 6) modification of the design where necessary.

The principal application of this study is the upper extremity in the quadriplegic subject. However, the technology being developed in this project is expected to be directly applicable to other neurological deficits, such as stroke and cerebral palsy, thus enabling researchers and clinicians to have a powerful new technique more available for rehabilitation of motor function.

An Externally Powered, Multichannel, Implantable Stimulator for Control of Paralyzed Muscles

P. Hunter Peckham, Ph.D.; Michael W. Keith, M.D.; Brian Smith, B.Sc.(Hons.)

Case Western Reserve University Rehabilitation Engineering Program; Veterans Administration Medical Center, Cleveland, OH 44106; Metropolitan General/Highland View Hospital, Cleveland, OH 44109

Sponsor: VA Rehabilitation Research and Development Service; National Institutes of Health

Purpose—This research is to develop a small patient-portable Functional Neuromuscular Stimulation System. The system which has been developed uses a flexible, programmable microprocessor control unit ("Portable Functional Neuromuscular Systems for Upper Extremity Control," reported on elsewhere in this issue) and an eight-channel radio frequency powered and controlled implantable stimulator unit. The initial target application of this implantable system has been the restoration and control of hand function in quadriplegic subjects. The system in this application incorporates major external elements of our present multichannel patient-portable stimulator that uses percutaneous electrodes.

Progress—The implant stimulator is an eight-channel device, powered and controlled over a transcutaneous radio frequency (RF) link. The circuitry has been realized using thick film hybrid circuit techniques, with the circuit design based on the use of a CMOS Semi-Custom integrated circuit. Command signals are serially input to the implant stimulator via the transcutaneous RF link. Each command elicits the output of a single electrode to be stimulated and the duration of the stimulus pulse. The rate of repetition of the command determines the interpulse interval. Each output channel is independent of the others and is a capacitively coupled biphasic stimulus with controllable amplitude (0.2 to 20 mA), pulse width (0 to 255 msec.), and

interpulse interval (infinite to 20 msec.).

The circuitry is packaged in a hermetic, laser-sealed, titanium capsule, having multiple feedthroughs. A stainless steel receiving coil is external to the package, connected to the circuitry by spot weld connections to the feedthroughs. Electrode leads are connected to feedthroughs at the opposite end of the capsule. This assembly is stabilized in medical-grade epoxy and coated in silicone elastomer. An unencapsulated area of the package is used as the anode. Size is 8cm x 3.5cm x 1cm, with an approximate weight of 40 grams.

The electrode lead wire consists of multistrand, stainless steel, teflon-insulated wires, that are helically wound in a close coil configuration. This wire coil is jacketed in silicone rubber tubing and filled with silicone rubber. In-line connectors are used on each lead wire. The connector consists of two male pins that mate with a center spring and are covered by a silicone elastomer tubing. The connector is flexible along its length, does not introduce large loads into the electrode leads, requires no special tools for opening or closing, and will withstand repeated opening and closing. Overall diameter is only slightly larger than that of the electrode leads, allowing placement of several connectors side-by-side in one implantation site. The lead wires are terminated at the stimulating electrode, which is a Pt/Ir epimyseal design. Encapsulation of the electrode provides for strain relief into the lead wire, a means of anchoring (suturing) the electrode at the

motor point, and directs the stimulus current into the target muscle body.

Preliminary Results—One device has been implanted in a human subject and has been operational for over nine months. We have also implanted 16 implantable stimulators in the forelimbs of dogs. Eight earlier devices were packaged, using a glass ceramic capsule, with the remaining devices implanted with the titanium capsule. Presently, we have three devices *in vivo*, which have been operational for 28, 23, and 22 months, respectively, as of July, 1987.

Future Plans/Implications—Our objective is to continue the development and evolution of the implantable system in animals and human subjects. Studies in animals are to develop implantation technique, evaluate long-term function, and determine methods of failure analysis. In-human studies are to evaluate the performance of the system in augmenting grasp/release function.

Publications Resulting from This Research

An Externally Powered, Multichannel Implantable Stimulator for Versatile Control of Paralyzed Muscle. Smith B, Peckham PH, Roscoe DD, Keith MW, Marsolais EB, *IEEE Transactions in Biomedical Engineering*, 1987.

Implantable Stimulator System for Control of Paralyzed Muscle. Peckham PH, Smith B, Buckett JR, Thrope GB, Keith MW, *Government Microcircuit Applications Conference (GOMAC)*, San Diego, CA, November 1986.

Elbow Control in the C5-C6 Quadriplegic Using Functional Neuromuscular Stimulation

P. Hunter Peckham, Ph.D.; Michael W. Keith, M.D.; Loris J. Miller, B.S.

Case Western Reserve University Rehabilitation Engineering Program; Veterans Administration Medical Center, Cleveland, OH 44106; Metropolitan General/Highland View Hospital, Cleveland, OH 44109

Sponsor: National Institutes of Health and National Institute on Disability and Rehabilitation Research

Purpose—The purpose of this project is to provide control of elbow position in the C5-C6 quadriplegic using electrical stimulation of the triceps muscle. Studies have focused on development of a system which uses stimulation to provide overhead reach.

Progress—Elbow control is compromised in an individual with a C5-C6 spinal cord injury due to loss of antagonistic control of the joint. While the elbow flexors remain under voluntary control, the elbow

extensors are paralyzed. When the elbow is below shoulder level, elbow position is controlled by allowing gravity to act as an elbow extensor; however, when the individual attempts to reach above this level, gravity acts with the elbow flexors and no forces are available to provide the needed elbow extension. By stimulating the triceps muscle, extension torques can be produced which allow overhead reach to occur.

A laboratory-based system has been developed

which provides the subject with control of elbow position. Control is obtained by establishing a relationship between the position of the arm and the level of stimulation delivered to intramuscular electrodes. The level of stimulation is always sufficient to overcome active, passive, and gravitational forces at the elbow and thus provide full elbow extension. If an intermediate position of the elbow is desired, the subject can use voluntary elbow flexion to counteract the stimulation-induced elbow extension torque. Since arm position alone determines the stimulation parameters, no additional conscious command is required by the user. This is an important feature if the subject is also using a system to provide hand grasp, which does require a conscious command control signal.

The sensors which furnish the position information are mounted on the upper arm and measure humeral abduction, humeral rotation, and elbow flexion angles. This position information provides the input parameters to a look-up table which stores the stimulus levels output to each electrode. The stimulus value was obtained from isometric force studies which determined the position-dependent passive torques about the joint as well as the extension torques which can be obtained from each

electrode at given positions. The position dependence of the gravitational torques is obtained from an analytical model which predicts the torque produced by the weight of the forearm and hand about the elbow joint. Thus, by knowing the position of the arm, the passive and gravitational torques which oppose elbow extension at that position are counteracted with extensor torques produced from the triceps stimulation.

Preliminary Results—One subject is currently working with this system in the laboratory. Two intramuscular electrodes have been implanted in each arm to provide the stimulation. Each electrode can produce torques sufficient to produce full elbow extension in any arm position. Studies are underway to determine the best stimulation parameters to ensure good control of the elbow without inducing muscle fatigue.

Future Plans/Implications—Experiments are under way to study subjects to reach overhead targets. We also plan to implement this system in the patient-portable system to provide both grasp and overhead reaching ability.

Analysis and Development of Coordination Programs for Hand Grasp in the Tetraplegic Using Functional Neuromuscular Stimulation

P. Hunter Peckham, Ph.D.; Michael W. Keith, M.D.; Kevin Kilgore, M.S.

Case Western Reserve University Rehabilitation Engineering Program; Veterans Administration Medical Center, Cleveland, OH 44106; Metropolitan General/Highland View Hospital, Cleveland, OH 44109

Sponsor: *National Institutes of Health*

Purpose—The purpose of these studies is to analyze methods for determining the optimal stimulus parameters for developing hand grasp movements during functional neuromuscular stimulation (FNS). This is to be achieved by measuring the force and/or position output generated by stimulation through individual electrodes and to sum force vectors to develop the coordination schemes that result in the desired grasp output.

Progress—Force vector output of the thumb generated by stimulation applied to each electrode is measured isometrically at a number of stimulation levels. A transducer that measures force in two

directions is positioned around the subject's thumb, and a stimulus is delivered through percutaneous intramuscular electrodes. The recruitment level is changed, using pulse width modulation, with the amplitude and frequency held constant. Stimulation is applied for three seconds, and the static force values are obtained by averaging the output over the last half second of the trial. The force magnitude and direction of electrically-induced force is then related to the stimulus input. Seven C5 and C6 level quadriplegic subjects have taken part in these studies.

Results—Force vector recruitment curves have been

obtained for electrodes in four thenar muscle groups. These muscle groups are: extensors (extensor pollicis longus, extensor pollicis brevis, abductor pollicis longus), median thenar intrinsics (abductor pollicis brevis, opponens pollicis, flexor pollicis brevis), adductor pollicis, and flexor pollicis longus. The recruitment curves were obtained in three thumb positions: resting, full extension, and full abduction. The results indicate that the force output changes in both magnitude and direction as the stimulus level changes. The results also showed that the direction of the force vectors at maximum stimulus rotated in the direction of pronation when the thumb is moved from the resting to the abducted position. When the thumb is moved from the resting to the extension position, the force vectors at maximum stimulation always rotated in the direction of

supination. The data obtained can be used to characterize the electrode/muscle combination output in terms of threshold, gain, direction of force, maximum force and length dependency. These parameters are important considerations in the development of grasp parameters.

Future Plans/Implications—Future plans include determining the feasibility of combining vectors from individual muscles by summing them mathematically to predict the total output when the two muscles are stimulated together. Active force measurements will be combined with measurements of passive force and joint position to determine if this information can be used to predict net resultant force of the thumb in grasp. We are also using this technique in the analysis of finger movement.

C. Lower Limb Applications

Electrical Stimulation of Osteogenesis Using Selected Techniques

Thomas J. Baranowski, Jr., Ph.D.; Myron Spector, Ph.D.; James Roberson, M.D.

Veterans Administration Medical Center, Rehabilitation Research and Development Unit, Decatur, GA 30033 and Department of Orthopaedics, Emory University School of Medicine, Atlanta, GA 30303

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This project involves the use of various selected electrical stimulation techniques for growth and repair of bone. The overall goal is to determine an effective technique to be employed in research planned to evaluate the appropriateness of electrical stimulation therapy to remobilize patients with loose prosthetic devices (trauma and irritation present) and patients with osteopenia (trauma and irritation absent). The specific aims are to: 1) define a dose response relationship in magnetic field amplitude for electromagnetic stimulation (EMS) produced by a sinusoidal waveform; 2) determine whether trauma and irritation are required with EMS produced by either a sinusoidal or a square-pulse waveform; and, 3) compare the efficacy of direct current stimulation (DCS), EMS by sinusoidal waveform, and EMS by a square-pulse waveform in the same animal model.

Progress/Methodology—Throughout this project, the tissue site selected for electrical treatment is the rabbit tibial medullary canal. Surgical intramedullary

insertion and implantation of a flexible, nonmetallic rod is used to produce trauma and irritation in intact tibia where indicated by experimental design. Such trauma and irritation may be required to elicit cells responsive to electrical stimulation treatment. The biological response within the medullary canal after electrical treatment is evaluated by histomorphometric quantitation of new bone formation, necrotic tissue, and selected cell types.

Originally, restraint and anesthesia of the animals, used previously by others in similar experiments, were to be employed in this research to permit daily placement of electrical devices and appliances as well as the stimulation treatment. However, the excessive restraint, prolonged anesthesia, and consequent inactivity of the animals usually results in a loss of weight, health, and, not infrequently, life. To avoid these complications, a system consisting of a jacket, tether, and swivel was developed to permit routine electrical stimulation treatment of animals with devices and appliances from any stim-

ulation technique. It was believed that such a system would help to establish a more accurate index of the biological response to electrical stimulation with *in vivo* models. The jacket-tether-swivel system allows the animal to have freedom of movement within its cage with access to both food and water *ad libitum*. A Group of 12 animals has completed treatment with electromagnetic stimulation by a sinusoidal waveform of three different amplitudes using the above system. The group sustained the treatment without restraint or anesthesia and there was no loss of weight, health, or life.

Preliminary Results—As a result of contact with the

edges of the external electrical appliances, skin irritation was observed in several animal cases. Traumatic periosteal bone formation was not found. The magnitude of new bone formation, necrotic tissue, and selected cell types within the medullary canal after electromagnetic stimulation is currently being evaluated by histomorphometric analysis.

Future Plans—One appliance required with electromagnetic stimulation, the coil pair, will be altered in overall size to prevent skin irritation. These new coil pairs, together with the jacket-tether-swivel system will be employed in the remaining experiments of this research project.

Fitness Improvements and Physiological Responses to FES Exercise

Roger M. Glaser, Ph.D.; Agaram G. Suryaprasad, M.D.; Satyendra C. Gupta, M.D.; Frank J. Servedio, Ph.D.; Glen M. Davis, Ph.D.; Stephen F. Figoni, Ph.D.; Mary M. Rodgers, Ph.D.; Bertram Ezenwa, Ph.D.

Veterans Administration Medical Center, Dayton, OH 45428; Department of Physiology and Biophysics, Wright State University School of Medicine, Dayton, OH 45435; Rehabilitation Institute of Ohio, Miami Valley Hospital, Dayton, OH 45409

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The overall purpose of this research project is to develop exercise techniques that incorporate functional electrical stimulation (FES) of paretic or paralyzed skeletal muscles to improve strength, endurance, hemodynamic function, and cardiopulmonary fitness of patients with spinal cord injury (SCI) or other neuromuscular dysfunction. The goals of this project are to evaluate the effectiveness of protocols that use: 1) only FES exercise of paralyzed muscles; 2) simultaneous combinations of FES-induced leg exercise and voluntary arm exercise; and, 3) simultaneous combinations of voluntary and FES-induced contractions of the same paretic muscles.

Progress—The 1986 progress report from this laboratory summarized the results of several studies that relate to muscular strength and endurance, as well as metabolic and cardiopulmonary responses to FES alone and FES combined with voluntary exercise ("hybrid" exercise). This current report focuses on three studies where FES-induced static or dynamic contractions of leg musculature were used to activate the venous muscle pump and enhance central hemodynamic responses of subjects during rest and/or arm exercise. In Experiment I, FES was applied to

the legs of ten able-bodied and six SCI paraplegic subjects to induce static pulsatile contractions of calf and thigh muscles during rest in the upright sitting posture. In Experiment II, twelve SCI paraplegics performed voluntary arm-crank exercise during both static pulsatile FES contractions (calf and thigh muscles) and FES-induced dynamic contractions of the rectus femoris muscles. In Experiment III, static pulsatile FES was performed during rest and arm-crank ergometry under various orthostatic loads on a tilt table. In each experiment, eight channels of static FES were applied bilaterally to rectus femoris, biceps femoris, gastrocnemius, and anterior tibialis, alternating between thigh and calf muscle groups at 1.5-sec intervals. Computerized real-time monitoring of central (cardiac) and peripheral (arm and leg) arterial blood flow is also being evaluated utilizing impedance cardiography and plethysmography.

Preliminary Results—In Experiment I, FES-induced contractions resulted in 12-30 percent increases in left ventricular stroke volume (SV) and cardiac output (CO) in both able-bodied and paraplegic groups. In Experiment II, the six paraplegic subjects who were most responsive to FES displayed 18-30 percent

higher SV and CO during simultaneous voluntary arm-cranking (0-90 watts power output) and FES-induced leg exercise (hybrid exercise) compared with arm-cranking alone. Additionally, the lack of heart rate and blood pressure changes between arm-crank exercise with or without FES suggests that the improved circulatory function was achieved with no increase in myocardial stress. During combined arm-cranking and dynamic FES knee extensions, blood lactate concentrations were lower than during arm-cranking alone, suggesting that the dynamic FES leg exercise improved lactate clearance and/or central hemodynamics. Preliminary results of Experiment III indicate that the FES-induced venous muscle pump increases venous return, SV and CO during rest and light arm-crank exercise during light-to-moderate orthostatic loading in SCI subjects whose leg muscles are most responsive to FES. This suggests that in SCI subjects, appropriately applied FES may reduce venous pooling/stasis and improve central hemodynamic responses to rest and exercise in the upright posture.

Future Plans/Implications—Our future research will focus on the short-term effects of FES on central and peripheral hemodynamics, and their interactions with posture and exercise. Additionally, we will

implement long-term exercise training programs using dynamic FES-leg cycling in combination with voluntary arm-cranking to maximize the benefits of cardiopulmonary fitness training. The improved circulatory state during FES may help prevent the potential medical complications of venous pooling/stasis such as deep venous thrombosis, pulmonary embolism, excessive edema, and orthostatic hypotension. The alleviation of circulatory hypokinesia during hybrid exercise due to venous pooling may also enhance arm exercise performance or lessen the stress of arm exercise such as wheelchair locomotion by improving blood flow to exercising upper body muscles.

Publications Resulting from This Research

Central Hemodynamic Responses to Lower-Limb FNS. Glaser RM, Rattan SN, Davis GM, Servedio FJ, Figoni SF, Gupta SC, Suryaprasad AG, *Proc. Ninth Ann. Conf. IEEE/EMBS*, 1987 (in press).

Effects of Electrically-Induced Paralyzed Leg Exercise on Hemodynamic Responses to Arm Crank Ergometry. Davis GM, Servedio FJ, Glaser RM, Suryaprasad AG, Gupta SC, *Med. Sci. Sports Exerc.*, 19(S):81, 1987.

Metabolic Responses to Arm Crank and Electrically-Induced Leg Exercise in Paraplegics. Servedio FJ, Davis GM, Glaser RM, Suryaprasad AG, Gupta SC, *Med. Sci. Sports Exerc.*, 19(S):19, 1987.

Functional Tasks Restored in Paralyzed Man Using Electronic Orthotics

E.B. Marsolais, M.D., Ph.D.; Rudolph Kobetic, M.S.; Howard Chizeck, Sc.D.; Wen Ko, Ph.D.; J. Mansour, Ph.D.; J.T. Mortimer, Ph.D.

Veterans Administration Medical Center, Cleveland, OH 44106, and Case Western Reserve University, Cleveland, OH 44106

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This program aims to restore functional tasks, such as walking and climbing and descending stairs, to individuals with paralyzed lower limbs. Further development of our existing neuromuscular orthotics system is focused on achieving smoother performance, improved stability, specific functional activity and reduced fatigue. A longer term goal is to provide the system in a fully implantable form.

Progress—Since 1982, eleven subjects, with neurologically complete spinal cord lesions between T4 and T11, have been able to stand, seven subjects have been able to walk, and three subjects have

been able to climb and descend stairs with the functional neuromuscular stimulation (FNS) system. Percutaneous intramuscular electrodes were implanted, by means of hypodermic needles, into 13 muscles bilaterally in the hips and legs. These electrodes received signals from a microprocessor-controlled muscle stimulator. Individualized stimulation patterns were developed and modified as needed to allow gait practice, functional activities and laboratory experimentation.

Preliminary Results—In the past year, the development of a new method for implantation enabled

successful implantation of electrodes with a reduction in the number of trials necessary for each implant from 3.3 to 1.25. The portable stimulator was redesigned to allow inclusion of six surface electrodes placed on the lower back, which were added to improve trunk stability. Addition of the surface electrodes enabled subjects to walk for longer distances before they fatigued.

A new portable stimulator based on the V40 NEC microprocessor with 48 channels of stimulation was designed and built to allow expansion of the system. A miniature prototype joystick for subject command input was designed and built to enhance ease of selection of functional activities. New stimulation patterns were developed for backstepping, sidestepping, and pressure relief while seated. Effects of trunk stimulation on hip extension and abduction were tested and showed considerable increase in torques over hip stimulation alone.

Development and testing of closed-loop controllers for lateral motion at the hip was carried out. Prototypes of linear sensors and pressure sensors

to provide feedback signals for closed-loop control of stimulation were tested both in the laboratory and on human subjects.

Design modifications were made to the ankle-foot orthoses used by all paraplegic subjects in order to protect against possible foot and ankle damage due to inversion of the foot. An instrumented garment of elastic material was designed and modified to include both surface trunk electrodes and connectors to intramuscular electrodes.

Future Plans/Implications—We plan to: 1) improve the anchoring properties and the resistance to material fatigue of the intramuscular electrodes; 2) develop new stimulation patterns for additional functional tasks, particularly maneuvering in small spaces; 3) test controller designs with computer simulation prior to implementation and compare to the open-loop system; and, 4) miniaturize the best controller, interface it with existing sensors, and integrate it into the current portable stimulators for use outside the laboratory.

Functional Tasks Restored in Paralyzed Man Using Electronic Orthotics (Project Extension)

E.B. Marsolais, M.D., Ph.D.; Rudolph Kobetic, M.S.; Howard Chizeck, Sc.D.

Veterans Administration Medical Center, Cleveland, OH 44106 and Case Western Reserve University, School of Medicine, Cleveland, OH 44106

Sponsor: VA Rehabilitation Research and Development Service (Project #XB193-4RS)

Purpose—The feasibility of using functional neuromuscular stimulation (FNS) to provide basic mobility for paralyzed persons in the laboratory has been clearly demonstrated by work at the Cleveland Veterans Administration Medical Center during the past four years. The overall objective of the proposed program is to develop FNS systems which will provide paralyzed persons with independent mobility and useful function, such as walking, climbing and descending stairs, and maneuvering in small spaces—capabilities that will enable them to increase their level of independence in the community.

Two phases of clinical application are planned. Towards the middle of the proposed funding period, we will evaluate clinically the open-loop version of our FNS system in individuals with partial paralysis from either incomplete spinal lesions or cerebrovascular accidents. To achieve this objective, sev-

eral specific goals must be met. Improvements in electrode design and implantation techniques for both percutaneous and implantable systems to increase system reliability and repeatability are essential. Similarly, the hardware components of the system must be miniaturized and made more reliable, robust, user-friendly, and cosmetically acceptable before clinical trials can begin. Open-loop software sequences for functional tasks must also be developed and/or refined.

Parallel with these developments, we will design and test the transducers and controllers necessary to create a closed-loop system capable of adjusting to changes both in the internal and external environments; such a system will allow a reduction in the total amount of stimulation delivered to the muscles, hence delaying the onset of fatigue. Stimulation algorithms for joint motion and for integra-

tion and coordination of all joint controllers as well as for reducing muscle fatigue must be developed. The implementation of these closed-loop components together with the developments described above will increase the usefulness offered by our FNS system by providing standing and ambulation capabilities, increased stability, reduced metabolic

energy costs, and reduced muscle fatigue and by increasing its reliability and user-acceptance. We anticipate that this system will be available for implantation and clinical evaluation in individuals with complete spinal cord lesions at the end of the proposed funding period.

EMG as Force-Feedback in Closed-Loop Functional Electrical Stimulation

C.P. Mason, M.S., and J.A. Gruner, Ph.D.

Veterans Administration Medical Center, New York, NY 10010 and New York University Medical Center, New York, NY 10016

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is to develop a closed-loop, functional neuromuscular stimulation (FNS) system to improve dynamic force and position control of paralyzed limbs. Closed loop control should greatly increase the functional capabilities and performance of FNS systems and earn greater patient acceptance.

The cat limb segment from the knee to the ankle, including the gastrocnemius, plantaris, soleus, tibialis anterior muscles and the tibial nerve (TN) is sufficiently similar to the human to serve as the *in vivo* model for exploring the relationship between nerve stimulation, muscle force, and myoelectric response. The TN was first stimulated using nerve cuff (NC) electrodes and the force generated about the ankle was monitored. The TN was then divided into its natural fascicles which innervate the muscle subdivisions (heads and compartments). The fascicles were stimulated with platinum hook electrodes. Constant current, bipolar, rectangular 100 microsecond pulses of variable amplitude with a 5-second interpulse interval were used. Intramuscular electrodes were used to monitor electrical activity at 3 points along each muscle subdivision. The electrodes pairs were placed 3 mm. apart along the muscle fibers with 1 mm. of bare wire at the tips and 13 mm. between pairs.

Progress—Computer hardware and software for recording and digitizing up to 16 EMG signals and 4 force, position and torque channels has been implemented. A 16-channel EMG preamplifier has been designed, fabricated, and calibrated. Data reduction analysis and display programs are being developed.

Results—Nerve cuff stimulation of the TN typically resulted in an EMG range from 2.5 to 25 millivolts peak-to-peak, and a force range from 50 grams to 1.2 kilograms. There was little evidence of hysteresis with increasing versus decreasing stimulus amplitude. Changing stimulus polarity primarily altered the threshold level. In some cases, EMG responses as a function of stimulus amplitude, were non-monotonic due to changes in the shape of the EMG waveforms, i.e., phase reversal, with increasing stimulus current.

Activation of individual muscle subdivisions was achieved by dissecting apart up to seven nerve bundles (fascicles) of the TN before it enters the gastrocnemius and soleus muscles. The locations of the recording electrodes in each muscle were verified by direct muscle stimulation. Stimulation of the individual fascicles showed the lateral gastrocnemius to have more than one independent compartment as described by A.W. English (Emery University). However, there was some apparent cross-stimulation from one bundle into two compartments, and one nerve bundle was found to generate no force.

Analysis of peak-to-peak EMG's of the independently-stimulated muscle subdivisions revealed high correlations between peak-to-peak EMG response, force, and stimulus current within the range of contraction threshold to 95 percent maximum force output. The linear first-order correlation coefficients of peak-to-peak EMG versus force in the active compartments varied from 0.76 to 0.99. Using the average of the peak-to-peak EMG's of the active compartments, the relationship was 0.98. The cor-

relation coefficient was slightly higher between force and total combined peak-to-peak EMG than between force and stimulation current.

Future Plans/Implications—Understanding the relationship between the factors of electrode location, electrode orientation, and muscle compartmentali-

zation, along with the technique of sampling multiple muscle subdivisions, should improve FNS feedback control. However, it should be noted that the muscle EMG response is independent of muscle length and therefore a method of internally measuring the muscle length is needed to utilize EMG feedback in non-isometric conditions.

Computer Models for Designing Functional Electrical Stimulation Systems for Paraplegic Standing and Walking

Felix E. Zajac, Ph.D. and Inder Perakash, M.D.

Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Our long term objective is to develop computer tools to assist the rehabilitation team in designing user-specific FES-control systems so that paraplegics can stand and walk.

Progress—We have:

1) **Generated a computer model of FES-induced paraplegic standing assuming bilateral symmetry (i.e., only sagittal plane motion).** The dynamic equations of motion for a three body-segment model (shank, thigh, torso) were developed. The dimensionless dynamics of musculotendon contraction, driven by an activation signal, was also developed. A convenient, analytical relationship between the pulse-stimulus parameters (i.e., pulse-width, or -amplitude, and time between stimuli) and the muscle's activation signal was derived. The basic structure of our dimensionless musculotendon actuator model is consistent with the notion of a memoryless element (given by the electrode's "recruitment curve") followed by a dynamic element (musculotendon contraction dynamics), and is therefore directly related to FES-control parameters. The musculoskeletal geometry for 18 muscles of the lower extremity was also modeled. Nominal parameters specific to each musculotendon actuator (muscle strength, muscle-fiber length, muscle-fiber pinnation angle) were found from the literature. Our effort focused on the development of a procedure for ascertaining the resting (slack) length for each of the 18 tendons. Special attention was also given to knee biomechanics, and how the patella affects the force to joint-torque transformation. Combining all these constituent relationships, we were able to

develop the nonlinear state equations for this 3-segment, sagittal plane representation of the body.

2) **Generated a computer graphics display that shows in real- (or slowed-) time how the body moves in the sagittal plane when FES is employed to induce standing in paraplegics.** The dynamic display shows how the body responds when the arms are unexpectedly moved (such as might occur when paraplegics voluntarily move their arms) using a feedback controller that applies FES to the paralyzed leg musculature. In addition, we have also been able to display how a paraplegic would be expected to rise from a chair using the same feedback controller (i.e., the feedback controller is trying to restore the paraplegic to the upright posture). The display is shown on a high performance workstation well-suited for fast, dynamic color display of 3-D objects (though only 2-D objects are currently being displayed). We developed graphics computer-code for displaying the body skeleton. Musculotendon actuators (each represented as a series collection of straight lines) can be displayed simultaneously, in red if the muscle is excited and in blue otherwise. The multiple-windowed display is menu-driven so that data (e.g., 2-D curves of body-segmental positions, velocities, accelerations, joint torques) can be shown simultaneously. We have found that such graphic displays offer invaluable insight into the dynamic interactions occurring during FES-induced standing.

3) **Developed a feedback control law for FES-induced standing, assuming motion in the sagittal plane only.** We assumed that joint angles and velocities can be measured (or estimated in the control

sense) and are available for feedback control. The state equations were linearized around the upright posture. A constant-gain feedback-controller was designed using linear optimal control with a quadratic cost function. This cost function is, in effect, the sum of the cumulative deviation from the upright posture and the cumulative amount of torque consumed, assuming a specific relative weighting of these two deviations. To find a unique feedback control we optimized average performance over the whole set of possible initial states. We showed, through computer simulation, that this feedback law developed by linearizing the nonlinear musculoskeletal system, when applied to the actual nonlinear musculoskeletal system, performs remarkably well in restoring the upright standing posture, even from a sitting position with all muscles initially inactive. There is one caveat, however. We use a minimization of energy criterion to partition the summed (net) muscle joint torques found from the feedback controller into specific muscle torques. At the moment, the computational time required to do this partitioning is much too long to be practical.

Future Plans—We expect to study the sensitivity of computer-simulated standing performance in the sagittal plane to perturbations arising from arm

movement and arm contact forces, such as occur during opening a door or removing a book from a shelf. We will also study the sensitivity of standing performance in the sagittal plane to the number and kind of muscles available for FES, to muscle strength, and to anthropometry.

Publications Resulting from This Research

Musculotendon Actuator Models for Use in Computer Studies and Design of Neuromuscular Stimulation Systems. Zajac FE, Topp EL, Stevenson PJ, *Proceedings of the 9th Annual Conference on Rehabilitation Technology*, 6:442-444, Minneapolis, MN, June 1986.

A Planar Musculoskeletal Model for Studying Posture Induced by Functional Neuromuscular Stimulation. Khang G, Zajac FE, *Proceedings of the 9th Annual Conference on Rehabilitation Technology*, 6:445-447, Minneapolis, MN, June 1986.

A Musculoskeletal Model of the Human Lower Extremity. Gordon ME, Hoy MG, Zajac FE, MacLean KE, *Proceedings of the 9th Annual Conference on Rehabilitation Technology*, 6:448-450, Minneapolis, MN, June 1986.

Simulation of Paraplegic Postural Control Induced by Functional Neuromuscular Stimulation. Khang G, Zajac FE, *Proceedings of the 10th Annual Conference on Rehabilitation Technology*, 7:636-639, San Jose, CA, June 1987.

The Effects of Patellar Size and Patellar Ligament Length on Knee Joint Mechanics: Implications for Rehabilitation. Yamaguchi GT, Zajac FE, *Proceedings of the 10th Annual Conference on Rehabilitation Technology*, 7:843-845, San Jose, CA, June 1987.

Development of an Improved Walking System for Paraplegics with FES Adjunct to the LSU Reciprocating Gait Orthoses

M. Solomonow, Ph.D.; R. Douglas, C.O., Ph.D. (Hon.); A. King, M.D.; H. Shoji, M.D.
Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: LSU Department of Orthopaedics

Purpose—The objective of this project was to provide paraplegics with a reliable and safe walking system with reduced metabolic energy consumption by utilizing electrical stimulation of selected muscle groups.

Progress—While the LSU brace has been successfully applied for a number of years to a large population of paraplegics, work has been expanded mostly on development of two FES strategies designed for use in synergy with the LSU orthoses.

The first approach employed surface stimulation of the quadriceps simultaneous to the contralateral gluteus maximus to induce hip flexion and extension. The second approach employed implanted stimulation of the iliopsoas muscle for more powerful hip flexion. One patient has been tested and evaluated following the animal work reported previously.

Future Plans—Work continues on the final development of both approaches on a selected patient group.

Feedback Control of Hand Grasp During Functional Neuromuscular Stimulation

P.E. Crago, Ph.D.

Case Western Reserve University and Cleveland Metropolitan General/Highland View Hospital,
Cleveland, OH 44109

Sponsor: National Institutes of Health

Purpose—The objective of this project is to incorporate feedback control into palmar prehension/release and lateral prehension/release FNS hand grasp systems developed for C5 and C6 quadriplegic patients.

Progress—A single-degree-of-freedom stiffness regulation feedback control system is currently being implemented for both palmar and lateral pinch. In each grasp, several muscles are activated. Some of these are controlled in an open-loop fashion while others are under feedback control. The choice of which muscles to place under feedback control is made on the basis of function. Muscles that are important in the gradation of movement and/or force are under feedback control. Those muscles that act to stabilize a digit as a platform are not under feedback control. For palmar prehension-release, the finger flexors and extensors are under feedback regulation. The median thenar intrinsics and the thumb extensor are activated to hold the thumb in opposition. For lateral prehension-release the thumb muscles are under feedback control while the finger flexors and extensors are controlled open loop.

The input to the system is derived from the patient by a command transducer (typically measuring shoulder movement). This command is directly mapped to the stimulus pulse widths to be applied to the muscles that are under open-loop control. The patient-generated command is also converted

to a position command for the closed-loop portion of the system by a command map. For the case of lateral prehension, the lower 10 percent of the command range is used to bring the fingers from the extended to flexed position. Throughout this range, the position command for the thumb is fixed in extension. The remainder of the patient command range is mapped in a straight line, with increasing patient command specifying a decreasing amount of position command (i.e., movement in the flexion direction).

The stiffness regulator provides control of the relation between force and position of grasp under a wide range of mechanical loading conditions rather than just force or position alone. Two important features of the controller are: 1) that the properties of the load determine the relative contributions of force and position to the total feedback signal; and, 2) that only a single command is needed to control the grasp.

Preliminary Results—To date, the complete system has been implemented in software and studies with patients have begun to develop a rule-based tuning procedure. Performance of the combined open- and closed-loop-system will be measured in the laboratory during computer control of the system and during patient use of the system to pick up and manipulate objects.

Physiological Benefits of Electrical Stimulation of Paralyzed Muscle

Jill Fallen; P. Edmond; T. Dick; E.G. Walsh

Edenhall Hospital, Musselburgh, East Lothian, Scotland

Sponsor: Scottish Home and Health Department

Purpose—The aim of this project was to investigate the physiological effects of electrical stimulation of paralyzed muscle. The physiological parameters to be studied were the responses of muscle bulk, skin blood flow and spasticity to muscle stimulation in recent injury and established injury paraplegics.

Progress—A program of quadriceps stimulation was applied to recent injury and established injury paraplegics with complete spinal cord lesions between T1 and T10 for 16-46 weeks. Changes in muscle bulk were followed by measuring thigh circumference and skin blood flow was monitored using a

Laser Doppler Flowmeter. Muscle tone was assessed using a newly developed machine for torque induced motion analysis.

Preliminary Results—Daily electrical stimulation of paralyzed muscle in established injury subjects caused increases in thigh circumference (9.4 ± 0.9 percent) within 11-16 weeks. In recent injury subjects, the usually rapid muscle wasting was partially prevented by the use of electrical stimulation (daily following the onset of spinal injury). With continued muscle stimulation, initial thigh circumference (i.e., at time of injury) could be restored. If stimulation was begun after the initial wasting had occurred in these recent injury subjects, thigh circumference was again increased to preinjury dimensions.

Changes in skin blood flow in relation to the stimulation program were monitored in two ways: 1) The immediate response of skin blood flow on the thigh to the electrical stimulation was measured in both injured and noninjured subjects after a 15-minute period of quadriceps stimulation; the before and after flow levels being compared. In both groups of subjects, skin blood flow showed a transitory increase of 100-300 percent for 1-2 minutes. 2) Skin blood flow (thigh, foot, and arm) was measured weekly in the resting subject at two skin temperatures, normal temperature and at 44 degrees Centigrade. In the subjects measured there was no difference in skin flow at normal temperatures be-

tween noninjured subjects, paraplegics and tetraplegics. The skin blood flow response to the thermal stress test (i.e., at 44 degrees Centigrade) was also unimpaired in the spinal cord injured subjects. Stimulation appeared to cause a long-term increase in skin blood flow only in the recently injured subjects, no changes in skin blood flow being apparent over the weeks of the stimulation program in the established injury subjects.

In addition, foot skin blood flow reactions to passive head-up tilting (17 degrees) were also measured. Noninjured subjects showed a 42.0 ± 3.0 percent decrease in foot skin blood flow during this procedure. Paraplegics (T4-T8) had an unimpaired orthostatic response but tetraplegics (above T1) and subjects with low level lesions (T10-L3) showed a much reduced response skin blood flow only decreasing by 22.3 ± 2.9 percent upon tilting.

Future Plans/Implications—Further experiments are continuing in order to clarify the changes in skin blood flow which occur with the electrical stimulation. Assessment of muscle tone and spasticity in paraplegics and the influence of electrical stimulation upon it are also in progress.

Publications Resulting from This Research

The Effects of Changes in Posture on Skin Blood Flow in Paraplegics. Douglas AJ, Fallen J, Creasey GH, *Clinical Physics and Physiological Measurement* 8:82, 1987.

Hybrid Brace for Paraplegic Gait Restoration

William K. Durfee, Ph.D.

Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: *Whitaker Foundation, Health Sciences Fund*

Purpose—To design a neural prosthesis which restores gait, one must accurately control the dynamics of electrically-stimulated lower limb muscles. In this research, we are exploring a novel means of controlling the system by combining electrical stimulation with an orthotic lower limb brace which includes a friction brake at each joint. The motivation behind this concept is to negate the uncertainties in stimulated muscle force by adding a brace with known mechanical properties. The electrically-stimulated muscle then serves as an unregulated power source, with the orthosis regulating gait trajectory and stability.

Progress—We are developing this idea with stimulation experiments which control knee joint dynamics in able-bodied human subjects. We have built an experimental knee orthosis with a magnetic particle brake coupled to the joint and will make performance comparisons between voluntary knee motions, knee motions controlled by electrical stimulation alone, and knee motions controlled by combining electrical stimulation with the friction brake. If the concept appears feasible, we will design a complete, multi-joint leg orthosis for testing on spinal cord injury (SCI) subjects.

VIII. Functional Assessment

Portable Motorized Standing Aid

Gerald B. Kirschner, B.S.; Jung J.K. Noh, R.M.S.; Jack France, V.R.T./B.S.

Rehabilitation Medicine Service, Veterans Administration Medical Center, Asheville, NC 28805

Sponsor: VA Rehabilitation Research and Development Service

Purpose—It has been observed that there are a substantial number of disabled individuals who have great difficulty initiating movement from a seated to a standing position: once standing, they are able to ambulate with or without a walking aid. The purpose of this study was to develop a device which would allow the disabled to achieve a standing position without physical aid from another person.

Progress—To be effective, the device had to be portable, low cost, and applicable to various types of chairs. A search of the literature was made without finding a device that met our criteria. A variety of mechanical devices was considered, but due to the high torque load and the small space in which the mechanism must fit, many designs were rejected.

The first prototype was made; however, the physical size was over the required dimensions. Nevertheless, it was used to test the theory and practicality of the device.

Preliminary Results—Individuals with a variety of disabilities were tested (e.g., stroke, bilateral below-knee amputation, generalized weakness, rheumatoid arthritis). The results of the testing at this time have been positive.

Future Plans—A second generation standing aid is now at the fabricators. This device will be smaller than the first prototype. More extensive testing will be done.

Development of a Life Satisfaction Scale Applicable for People with Severe Disabilities

Steve M. Shindell, Ph.D.; Gregory L. Goodrich, Ph.D.; Michael Dunn, Ph.D.; Olga Overbury, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service and National Institute on Disability and Rehabilitation Research

Purpose—This study has developed a clinically useful structure interview that provides insight into the adjustment process of people with various disabilities. This was a longitudinal study of individuals enrolled in several inpatient rehabilitation programs of the Palo Alto VAMC (Western Blind Rehabilitation Center (WBRC), Spinal Cord Injury (SCI) Center, and Rehabilitation Medicine Services). A matched comparison sample of nondisabled veterans was also examined.

Progress—To date, the ACCESS questionnaire (Assessment of Current Community, Emotional, and Social Satisfaction) has been administered to over 1,200 patients and control subjects. The complete

series of interviews includes intake, discharge, and 6-month follow-up. In both the WBRC and SCI samples, 100 patients were interviewed who had actually received treatment 5 years ago. Data collection is complete in the WBRC sample, the 5-year SCI sample, and the control group. The current count on the SCI sample is: 66 intakes, 60 discharges, and 43 six-month follow-ups.

There are now 44 individuals in the Rehabilitation Medicine group. The original goal was to obtain at least 100 study participants in each group. We now project achievement of this goal in all but the Rehabilitation Medicine sample, where the final sample size will be 50.

Results—Preliminary results reveal a general high level of satisfaction with rehabilitation services provided within the VA, and a significant amount of psychosocial change during rehabilitation. This positive change appears consistent and stable over 6 months, and is comparable with matched control populations of people without disabilities as well as people that had rehabilitation over 5 years previously. The general quality of life of people with disabilities appears higher after rehabilitation, although many of the measures are still lower than the general nondisabled population.

Future Plans—Future plans consist of continued data collection and further analysis of existing data. In addition, dissemination of ACCESS in other research and clinical settings continues to be undertaken.

Publications Resulting from This Research

Determining Psychological Change During Rehabilitation Using the Standardized Interview ACCESS. Shindell S, Dunn M, Goodrich G, and Overbury O. Paper presented at the *American Psychological Association*, New York, NY, 1987.

Life Satisfaction Assessment. Shindell S. Paper presented at the *National Association for the Education and Rehabilitation of the Blind and Visually Impaired*, Chicago, IL, 1986.

An Investigation Into the Benefits of Upright Stance and Ambulation in the Severely Disabled

C. Ogilvie, F.R.C.S.; N. Messenger, B.Sc.; D.I. Rowley, B.Med.Biol., M.D., F.R.C.S.; P. Bowker, B.Sc., Ph.D., C.Eng., M.I.Mech.E.

North Western Orthotic Unit, Hope Hospital, Salford, M6 8HD, England

Sponsor: *Action Research for the Crippled Child, West Sussex, England*

Purpose—The benefits of upright stance are: improved bladder, bowel, pulmonary and cardiovascular function, a decrease in osteoporosis, and psychological advantages, as quoted by Rose (1972) and Carroll (1974). But neither gave any indication of the scientific basis of their statements. A similar beneficial tendency has been noted by members of the Orthotic Unit during their association with patients in the swivel walker. Griffiths (1977) published work showing the improvement in pulmonary function that occurred going from wheelchair to swivel walker.

Progress—This project involves fitting patients, who are either congenital or traumatic paraplegics, with the Reciprocating Gait Orthosis (RGO). Most patients had previously been chair-bound, but in the case of some young children, this was their initial walking orthosis allowing upright stance and mobility. All patients have an initial clinical assessment by a surgeon and physiotherapist to check general fitness and to identify any deformities that may preclude the fitting of the orthosis. If present, these would be surgically corrected if possible, to allow the patient to be accepted for the pre-training program. All the patients enter a pre-training program of frame-standing and physiotherapy to achieve

balance and maximize their upper-limb strength.

The physiological tests performed are pulmonary function, that is, vital capacity, F.E.V. 1 and peak expiratory flow rate. The older patients have an EKG and chest X-ray as necessary. Blood investigations are full blood count, urea and electrolytes, and a bone profile. An ultrasound assessment of the urological tract is also performed and a mid-stream urine specimen cultured. These investigations are performed, initially, at the commencement of the pre-training program and are repeated at regular intervals. Psychological testing, using the Revised Weschler Intelligence Scale for both adults and children and Locus of Control tests (adults—Rotter; children—Nowicki and Strickland) are also performed at this time. These tests are repeated when the patient has been ambulant in the RGO for six weeks and will then be repeated again, after approximately six months' use of the RGO.

Preliminary Results—We have so far recruited eight patients for this study, six adult (over 16 years) and two children and baseline tests have been performed. More patients are being assessed for the RGO and recruiting will continue. The patients will also, when trained and adept in the use of the RGO, have energy costings performed, using the Physiological Cost

Index (PCI) method. This method has been chosen as there is no cumbersome apparatus to hamper the patient in the use of the RGO, only a small radio telemetry system.

Future Plans/Implications—It is hoped that it will be possible to monitor changes in the bone density of

patients in the future, using CAT-scanning techniques. The project is long-term in nature, but it is hoped to be able to give some preliminary physiological and psychological results in the short term. Hopefully, some prescription guidelines will be produced.

New Motor Control Assessment Techniques for Evaluating Individuals with Severe Handicaps

Nathan J. Rudin, M.S.; L. Donald Gilmore, A.B.E.E.; Serge H. Roy, M.S.; Carlo J. De Luca, Ph.D.
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Boston University; Liberty Mutual Insurance Company; VA Rehabilitation Research and Development Service*

Purpose—In 1985 we embarked upon a complex evaluation program with a severely handicapped nonvocal cerebral palsy patient, with the goal of developing a specialized interface for use with an assistive communication device. In order to accomplish this, a motor control assessment procedure (MCAP), combining clinical observation methods with computer-aided motion analysis, was developed. MCAP examines two types of information which may be used for device control: myoelectric activity at various muscle sites, and the displacement of body parts in space. Special assessment tasks are used to evaluate systematically the patient's motor abilities in quantitative terms that lend themselves to the design and construction of assistive devices.

Progress—The myoelectric assessment was completed in late 1985. Myoelectric activity proved not to be a practical device-control method for the current subject. For the past year, the focus has been on the evaluation of spatial displacement; specifically, rotation of the head, which appears to be the most practical control site for this particular patient. A motion transducer was constructed to

measure head rotation in the horizontal plane. Using the transducer, the patient and several normal subjects were asked to perform a series of head movement tasks, including tracking periodic patterns of movement and pointing to various targets on a computer screen. Software was written to identify and analyze typical patterns of head movement for normal subjects, including slopes, velocities, and ranges of motion, and to compare them to the patient's performance. The results indicate that the patient possesses sufficient proportional control of head rotation to operate a communication device.

Future Plans—We will continue our efforts by performing a final in-depth assessment of the patient's head movement using WATSMART. The data from WATSMART will be used as guidelines for the design and fabrication of a practical head interface tailored precisely to our subject's needs and abilities.

Publication Resulting from This Research

New Motor Control Assessment Techniques for Evaluating Individuals with Severe Handicaps. Rudin NJ, Gilmore LD, Roy SH, De Luca CJ, *Journal of Rehabilitation Research and Development* 24(3):57-74, 1987.

Comparative Evaluation of Body Support Systems for Tissue Pressure Distribution

Steven I. Reger, Ph.D., and Thomas McGovern, M.S.
Department of Musculoskeletal Research, The Cleveland Clinic, Cleveland, OH 44106

Sponsor: *Cleveland Clinic Research Foundation*

Purpose—Four commonly used hospital mattresses were evaluated by 10 normal subjects for their ability

to change the interface pressures in the recumbent position.

Progress—The subjects were classified according to sex, body weight, and height. Pressure measurements were made in the supine position and the side-lying position, using the Gaymar, Scimedix, and the TIRR pressure transducers.

The four supports studied were the Geomat, the Akros, the Sof-care 402, and the standard hospital mattresses (as the control). A hospital bed, adjusted horizontally, was used to support all mattresses during measurements. Three pressure measurements were taken at each anatomical location with the transducer repositioned between each measurement and the highest of the three measurements reported as the maximum local pressure. When averaged over the 10 subjects, the mean and its

standard deviation is given as the mean maximum local pressure.

Preliminary Results—Data analysis is in progress to describe the relation between mattress types, transducers and anatomic sites using analysis of variance, F-test, and the Duncan multiple-range test for comparisons of means.

Using additional mattresses, further work is continuing at the request of the Nursing Service at CCF. The results will be utilized by the Enterostomal Therapy and the Cardiovascular Nursing Services for the development of improved care toward the prevention of decubitus ulcers.

Validation of a Gross Motor Function Measure (GMFM) for Assessment of Outcome in the Treatment of Cerebral Palsy

P. Rosenbaum, M.D., F.R.C.P.(C)

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: The Easter Seal Research Institute, Toronto, Canada

Purpose—The objectives of this study are: 1) to evaluate the responsiveness to change of a gross motor function assessment measure (GMFM) for children with chronic neuromotor disabilities; and, 2) to compare several methods of quantifying motor function in order to compile a meaningful score which reflects actual performance in this population.

Progress—During the past 2 years, this study has evaluated the motor function of 140 children with neuromotor disabilities, and 30 normal children, at two points in time separated by three to six months. At the same time, judgments of change in motor function have been obtained from parents and therapists. The purpose of these judgments is to compare them with change scores on the GMFM in order to validate the responsiveness of the measure to change. In addition, 30 children have been videotaped on two occasions, for evaluation by trained physiotherapists “blind” to the “before-after” status of the children. This latter evaluation will add further validity to the results of the study.

This project has involved approximately 12 physiotherapists at the two centers, and represents a major collaborative effort in measurement development. The instrument is designed to capture

quantity of change in function, but has not attempted to assess quality of movement (performance).

Preliminary Results—Preliminary analysis of data from the GMFM study of 170 children indicates that the measure has good inter-rater reliability (values at or above 0.85 on several dimensions). The validity of the measure, with respect to its responsiveness to change, appears very strong. The correlations of change scores on the GMFM with therapist and parent judgments of change are consistently high (0.5 to 0.65), and are in fact much stronger than initially predicted when the study was being developed. It is therefore clear that we have created a measure of gross motor function which will be valuable in assessing change in the abilities of children with cerebral palsy.

Future Plans/Implications—The results of the study will be presented at an international scientific meeting and published in a major medical journal during the forthcoming year. In addition, a request for funding will be submitted to develop a measure of motor performance assessing quality of movement for use with children with neuromotor disabilities along with the GMFM which was not designed to capture the qualitative aspects of movement.

Pre-Clinical Research in Neuromuscular Diseases and Muscle/Nerve Biology

Richard K. Enrikin, Ph.D.

University of California, Davis, CA 95616

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The goal of this project was to quantitatively evaluate neuromuscular function and its use in assessment of physical and pharmacological intervention modalities. To reach this goal, the objectives were to: 1) characterize and classify functional, contractile, morphological, histochemical, and biochemical characteristics of skeletal muscle and other organ systems in animals with naturally occurring and induced neuromuscular disorders; 2) evaluate various physical and pharmacological interventions for possible beneficial effects on these disorders; and, 3) determine, through close interaction with clinical projects, the potential for application to rehabilitation of patients with neuromuscular disorders.

Progress—Quantitative procedures were developed to objectively measure functional, contractile, and histochemical properties in chickens and mice with neuromuscular disorders. An extensive database system was developed to manage, access, and analyze all data. Work on development of a computerized, quantitative EMG analysis system continued, and a system to induce hypokinesia in hind limbs of mice was completed.

Results—Computer-generated plots of muscle fiber areas verified the subjective impression that high variability of fiber size is a major characteristic of inherited neuromuscular disorders in chickens and mice. The first study of older (18-month) dystrophic chickens revealed that: 1) the histopathological changes in avian dystrophy are clearly progressive; 2) those changes closely resemble those seen in human Duchenne dystrophy; and, 3) a high degree of fiber splitting occurs in late stages of avian dystrophy. One form of exercise (high-repetitive,

sub-maximal) was found to partially alleviate signs of murine dystrophy. The first contractile and electrophysiological studies of the recently-discovered "myotonic" mouse showed that this hereditary condition faithfully reproduces the major features of human myotonia congenita. Studies of the newly-discovered *mdx* (sex-linked) mutant in mice suggest that this may be a useful model of muscle fiber regeneration, but that it is dissimilar to the major sex-linked human dystrophy (Duchenne). A drug evaluation program that utilizes the dystrophic chicken consistently identified one class of compounds (glucocorticoids) as highly effective against major signs of the avian dystrophy. As a result of that finding, a corticosteroid was recently evaluated in a multi-clinic trial involving patients with Duchenne dystrophy. As predicted from the chicken studies, the compound was effective, but its clinical utility is limited due to dose-limiting adverse effects.

Publications Resulting from This Research

Effects of Passive Stretch on Muscle Contractility of Normal and Dystrophic Chickens. Abresch RT, Sharman RB, Enrikin RK, Larson DB, Fowler WM, Jr., *Muscle and Nerve* 9(5S):249, 1986. (Presented at VI International Congress on Neuromuscular Diseases, Los Angeles, CA, July, 1986.)

Therapeutic Trials in Muscular Dystrophy of the Chicken: Phase-II Effects on Plasma CK Activity and Muscle Histology. Enrikin RK, Larson DB, De La Vega D, Abresch RT, *Muscle and Nerve* 9(5S):271, 1986. (Presented at VI International Congress on Neuromuscular Diseases, Los Angeles, CA, July, 1986.)

Therapeutic Trials in Muscular Dystrophy of the Chicken: Phase-I Effects on Muscle Function. Enrikin RK, Levine NA, Atwal B, De LaVega D, Robles M, *Muscle and Nerve* 9(5S):271, 1986. (Presented at VI International Congress on Neuromuscular Diseases, Los Angeles, CA, July, 1986.)

Contractile and EMG Studies of Murine Myotonia (mto) and Muscular Dystrophy (dy/dy). Enrikin RK, Abresch RT, Sharman RB, Larson DB, Levine NA, *Muscle and Nerve* 10:293-298, 1987.

Clinical Research in Neuromuscular Diseases

William M. Fowler, Jr.; Edmund Bernauer, Ph.D.; Janet Lord, M.D.; Margaret Portwood, M.D.; Robert G. Taylor, M.D.

University of California, Davis Medical Center, Sacramento, CA 95817

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—The purpose of this research is to describe the natural course of neuromuscular diseases (NMD) with quantitative measurements of selected major characteristics, and evaluate effects of various therapeutic interventions on these characteristics and the natural course of the diseases.

Progress—Procedures were designed to measure the complications of weakness, limb contractures, spinal deformity, restrictive lung disease, cardiac function, neuropsychological function, and functional ability. A comprehensive and objective battery of measurements has been developed to describe the natural course of each NMD and to serve as the criteria against which the effectiveness of therapeutic interventions can be determined.

Results—About 400 individuals with various NMD's have been evaluated.

Weakness: In boys with Duchenne dystrophy (DMD), manual muscle test (MMT) scores were related to age in a logarithmic fashion. Using quantitative measurements, isokinetic testing yielded the most information on dynamic functional strength. Patients had about 50 percent of the isometric strength of normal controls, and, with the exception of those with myotonic dystrophy (MMD), demonstrated greater fatigability. When compared to MMT's, muscle groups demonstrating normal strength exhibited widely variant objective strength scores, but compared favorably for weak muscles. There was no correlation between MMT scores and measurements of endurance. Contractile measurements showed that MMD patients had a marked impaired relaxation, reduced tetanic tension development, and a significant post-tetanic potentiation of the twitch when compared to normal age-matched subjects.

Limb contractures: Contractures were severe and rapidly progressive in DMD and spinal muscular atrophy (SMA), but insignificant in other neuromuscular diseases.

Spinal deformity: 56 percent of DMD patients,

67 percent of those with Friedreich's ataxia (FA), and 55 percent of those with SMA had significant scoliosis. Only 15 percent of other patients had spinal deformity.

Restrictive Lung Disease: Patients with DMD and amyotrophic lateral sclerosis (ALS) showed diminishing pulmonary function with increasing disease duration. In DMD, VC dropped to levels of severe impairment between the ages of 12 and 14. In patients with slowly progressive neuromuscular diseases, there was no relationship between disease duration and pulmonary function.

Cardiac function: Abnormal EKG's occurred in 92 percent of DMD and MMD patients, 83 percent in Becker's dystrophy (BMD), 67 percent in Limb girdle dystrophy (LGD), and 53 percent in facioscapulohumeral dystrophy (FSH). In spite of the high incidence of abnormal EKG's, only about 15 percent had clinical findings of cardiac disease, and there was no correlation with age, disease duration, or severity of the disease.

Neuropsychological function: Significant cognitive defects were found in MMD and DMD patients but not in any of the other NMD's. Personality testing indicated that depression, while common, was not indigenous to a particular disease.

Functional ability: While there was a significant non-random relationship between UE/LE functional grade and strength, measurements were not entirely equivalent when evaluating an individual's clinical status. Upper extremity functional scales correlated better with strength measurements than did lower extremity scales.

Publications Resulting from This Research

Intellectual and Cognitive Function in Adults with Myotonic Muscular Dystrophy. Portwood MM, et al., *Archives of Physical Medicine and Rehabilitation* 67:299-303, 1986.

Upper Extremity Functional Ratings for Patients with Duchenne Muscular Dystrophy. Lord JP, et al., *Archives of Physical Medicine and Rehabilitation* 68:151-154, 1987.

Upper Versus Lower Extremity Functional Loss in Neuromuscular Disease. Lord JP, et al., *Archives of Physical Medicine and Rehabilitation* 68:8-9, 1987.

Functional Ability and Equipment Use Among Neuromuscular Disease Patients. Lord JP, et al., *Archives of Physical Medicine and Rehabilitation* 68:348-352, 1987.

Differential Diagnosis of Muscle Diseases. Fowler WM, Taylor RG, *Musculoskeletal Disorders*, 2nd Ed., R. D'Ambrosia

(Ed.), Lippincott, 1986.

Depression in Myotonic Muscular Dystrophy. Duveneck MJ, et al., *Archives of Physical Medicine and Rehabilitation* 67:875-877, 1986.

Rehabilitation Management of Neuromuscular Diseases Research and Training Center, UC Davis

William M. Fowler, Jr., M.D.; James S. Lieberman, M.D.; Richard K. Enrikin, Ph.D.
University of California, Davis, CA 95616

Sponsor: *National Institute on Disability and Rehabilitation Research; U.S. Department of Education*

Purpose—The overall mission of this RT Center is to conduct a broadly-based, multidisciplinary program of research in the area of comprehensive rehabilitation management of neuromuscular diseases, and to initiate training that transposes the findings of this research into tangible products that rehabilitation practitioners and educators can use in service delivery and teaching programs. The purpose

of all research projects in the Center is to identify factors that prevent or limit successful rehabilitation, and develop intervention strategies to overcome those limiting factors. Specific research activities have been designed to function as a sequential series of clinical and pre-clinical projects grouped into two interrelated and correlated study sections.

Mobile Assessment Laboratory

Paul N. Hale, Jr., Ph.D., and Ronald L. Seaman, Ph.D.
Center for Rehabilitation Science and Biomedical Engineering, Louisiana Tech University, Ruston, LA 71272

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The goal of developing a Mobile Assessment Laboratory (MAL) is to provide a mobile facility for pre-assessment of a disabled person's capabilities for driving. The ability to deliver this service at sites convenient to potential drivers makes evaluation for driving more readily available to a group who may not be able to come to an evaluation center because of financial or scheduling reasons.

Progress—The MAL is a Collins Omni Baron window van on a Ford 350 chassis with a 138-inch wheel base. It is equipped with power steering, power brakes, air conditioning, automatic transmission, roof mounted 110-volt air conditioning and heating unit, and a Collins rear-mounted hydraulic wheelchair lift. Behind the driver's seat there is a space of 160 inch × 75 inch × 74 inch high for pre-assessment procedures. The space contains a complete second-generation Computer-Assisted Driver Assessment System with motion analyzer, functional strength analyzer, and tracking simulator. There is also an adjustable-height table to support

equipment and supplies for hearing, vision, and psychometric testing. Space limitations of the mobile unit have required only minor modifications in equipment layout and testing procedures used in the service-delivery area of the Center.

The MAL can be taken to areas far from rehabilitation centers to perform driver pre-assessments of disabled persons. The unit can be powered by a gasoline-powered portable generator at sites without adequate power connections. The entire MAL evaluation can be carried out by two professionals: a driver evaluator and an assistant. One to five clients can be served per day depending on extent of evaluation procedures necessary and distance traveled that day. In addition to its providing greater client accessibility to driver evaluation, it is anticipated that the MAL will offer substantial savings to driving candidates and their funding sources. By facilitating the overall assessment process, it has the potential to restore or to initiate independent driving in a cost-effective manner.

Results—The MAL has expanded the capabilities of the Center in several ways. The unit has traveled to ten different states throughout the country for purposes related to driver assessment/evaluation. Over 50 pre-assessments have been performed in the MAL using first- and second-generation assessment systems. The MAL has also been exhibited at several in-state and out-of-state conferences and used to teach rehabilitation professionals about driving by disabled persons.

Future Plans/Implications—MAL equipment and procedures will continue to be improved when user feedback indicates. The cost effectiveness of the mobile approach to pre-assessment of a disabled person's capabilities to drive will be evaluated in detail. Rehabilitation professionals in various states will be interviewed to determine the most appropriate use of the MAL in different state systems. It is anticipated that other types of assessments will also be feasible in the MAL.

Computer-Assisted Driver Assessment System

Paul N. Hale, Jr., Ph.D., and Ronald L. Seaman, Ph.D.

Center for Rehabilitation Science and Biomedical Engineering, Louisiana Tech University, Ruston, LA 71272

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The overall objective of the Computer-Assisted Driver Assessment System (CADAS) project is to provide an objective quantitative assessment of a disabled person's physiological capabilities for driving. Quantitative data are gathered on range of motion, functional strength, and tracking simulator performance. By providing this information, the CADAS aids a driving evaluator in determining whether a disabled person can drive a vehicle, if there is sufficient potential driving capability, and determine what vehicle modifications are necessary.

Progress—The Computer-Assisted Driver Assessment System comprises three major subsystems and a controlling computer. Two fully integrated second-generation systems using the IBM PC/XT micro-computer have been built and are operational. One system is located in the service-delivery area of the Center. The second system is part of a Mobile Assessment Laboratory equipped to perform pre-assessments of driving capabilities. Software in the C programming language records client personal information and controls and takes data from the three subsystems: the motion analyzer, the functional strength analyzer, and the tracking simulator. The modular menu-driven program also calibrates devices, guides assessment, manipulates and records data, and prints reports.

The motion analyzer has an extendable wand which is articulated in two planes. Wand length and angles in these two planes are detected by digital encoders. The system computer determines the

spherical coordinates of the wand tip by counting digital pulses from the three encoders. The computer presents a menu of up to 49 predefined points for characterization of client and wheelchair. The CADAS software produces a set of data and graphs that can be used by driver evaluator, drive educator, and vehicle modifier.

The functional strength analyzer is a steering wheel mounted rigidly on a shaft instrumented with strain gauges. The functional strength analyzer can assume a variety of configurations to measure forces on the steering wheel and on simulated hand controls. The static strength test, using the analyzer, measures the force applied to a steering wheel at various angles of tilt. The associated software provides menus to record data in a standard format.

The tracking simulator is a device developed at the Center to evaluate ability to track a target visually while using an assistive driving device. It can be configured to use several types of brake/accelerator and steering controls. The system computer, which also generates the target on a video monitor, displays the client's response according to the position of the controls the client is using. The result of the test is a set of measures of how well the client can track a target with different controls.

Future Plans/Implications—Refinements to design and operation of the three major CADAS subsystems, as well as the associated software, are based on user feedback. Ongoing efforts will result in a comprehensive technical report and a user's manual

covering CADAS. Ultimately, quantitative assessment information obtained from the CASAS will be used for comparison with a resident database of

assistive driving devices. From this comparison the computer will recommend devices to fit a client's needs.

Psychometric and Performance Predictors of Driving Ability

Paul N. Hale, Jr., Ph.D.; Ronald L. Seaman, Ph.D.; W. Drew Gouvier, Ph.D.

Center for Rehabilitation Science and Biomedical Engineering, Louisiana Tech University, Ruston, LA 71272 and Louisiana State University, Baton Rouge, LA 70803

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—The purpose of studying psychometric and performance predictors is to develop an accurate but efficient battery of assessment/evaluation tests for driving ability of the disabled person.

Progress—An initial study compared Visual React and Visual Search scores from the Cognitive Rehabilitation Test with scores of performing the seven maneuvers on the Center's tracking simulator. There were promising correlations between performance on two left-turn maneuvers and Visual React scores. Based upon these results, a larger study was designed to investigate the relationships between various cognitive tests and driving abilities.

A second study tested the predictive capability of eight standard cognitive tests and two Center-developed performance tests. The cognitive tests were Wechsler's Adult Intelligence Scale (WAIS), WPS Symbol-Digit, Halstead-Reitan Trail Making, Diller-Yishay Cancellation, Cognitive Rehabilitation Test (Visual React and Visual Search), Driver Performance Test (DPT), Baylor Adult Visual Perception Test, and Motor-Free Visual Perception Test (MVPT). The Center's two-dimensional tracking simulator, with its pursuit tracking tasks and Small-Scale Vehicle (SSV), were also included in the expanded battery of tests administered to subjects. Error scores from the tracking tasks and driving

performance scores on the SSV were considered as potential predictors of driving ability. The criterion measure in the study was the subject's ability to drive a full-size vehicle on a closed driving course. Efforts required to control the tracking simulator, the SSV, and the full-size vehicle were similar.

Volunteer subjects in the second study were assigned to three groups. There were ten traumatic-brain-injured, seven spinal cord injured, and eight nondisabled subjects in the study. With few exceptions, all tests were given to all subjects.

Preliminary Results—Results of the various statistical analyses indicated that an accurate prediction of driving ability can be made from a small number of tests of the disabled person. In fact, most results generalize across spinal cord injured, traumatic-brain-injured, and non-disabled persons. Preliminary results show the strongest predictors to be the Driver Performance Test, the oral WPS Symbol-Digit Test, and SSV performance. It also appears that the oral WPS Symbol-Digit, the Driver Performance Test, and the Visual React task of the Cognitive Rehabilitation Test were good discriminators of cognitive abilities among the groups tested. The findings support the feasibility of using a simple test battery to indicate which driver candidates are ready for in-vehicle assessment.

Small-Scale Vehicle for Driver Assessment/Evaluation and Training

Paul H. Hale, Jr., Ph.D.; Ronald L. Seaman, Ph.D.; Michael K. Shipp, M.Ed.

Center for Rehabilitation Science and Biomedical Engineering, Louisiana Tech University, Ruston, LA 71272

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—The goal of the Small-Scale Vehicle (SSV) project is to provide a cost-effective alternative to assessment/evaluation and training of disabled po-

tential drivers. By providing a low-threat, but realistic driving environment, the SSV facilitates evaluation of driving capabilities, familiarization with

assistive devices, and training on device use, vehicle operation, and driving behavior.

Progress—A second-generation SSV has been built and is currently being evaluated by current and potential users. The SSV is an electric golf car which has been extensively modified to incorporate a variety of control, safety, and instrumentation features. Although much smaller than a full-size vehicle, it offers a high degree of realism in terms of methods of steering and control, four-wheel design, and seating position. Its design permits the assessment and training of clients with a wide range of disabilities.

The steering system includes an adjustable steering column that allows the steering wheel to be positioned to meet the needs of the client. The system will accept any standard adaptive steering device. The adjustable reduced effort is a major feature.

The brake/accelerator functions are performed with the use of electronic modules or commercially available controls. Modules have been built to simulate the motions and efforts required to operate push-pull hand controls, push-right angle hand controls and servo-assisted push-pull and side-to-side controls. In addition, a floor-mounted push-pull quad control, a push-right angle hand control, and a left-foot accelerator can be installed. Standard brake and accelerator pedals are also operative. The brake system requires reduced effort to engage the brakes. An independent auxiliary braking system has been

added for the evaluator.

The seating system consists of automotive high-back bucket seats complete with restraining systems for the client and instructor. Overall safety features include a roll bar, warning lights and buzzers, fire extinguisher, circuit breakers, and drive motor cut-off switches.

A small-scale driving course is used for operation of the SSV. By driving the course under driver evaluator supervision, the operator experiences dynamic maneuvering challenges. The driver evaluator is able to determine effects of vehicle dynamics on driver performance in a controlled environment. The small-scale course requires about one-fourth the area of an equivalent full-scale course.

Results—The SSV Vehicle has proven to be a reliable, cost-effective, and meaningful approach to assessment/evaluation of the disabled driver.

Future Plans/Implications—The SSV will continue to be modified to meet the needs of users. Technological improvements will be made when higher efficiency, improved performance, or lower cost will result. It costs much less to purchase, operate, and maintain than full-size vehicles having the same assistive device capabilities. Space to house and to operate the SSV is much less than to operate a full-size vehicle. In some cases, on-the-road assessment/evaluation is completely eliminated, further reducing the need for a full-size vehicle.

Development of a Uniform National Data System for Medical Rehabilitation

Byron B. Hamilton, M.D., Ph.D., and Carl V. Granger, M.D.

Functional Assessment Study Center, State University of New York at Buffalo, Buffalo, NY 14203

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The uniform data system for medical rehabilitation (UDSMR) was developed to meet a long-standing need to document severity of patient disability and the outcomes of medical rehabilitation. Previously there has been no uniform way to describe and communicate about disability. This effort was jointly sponsored by the American Congress of Rehabilitation Medicine and the American Academy of Physical Medicine and Rehabilitation and endorsed or participated in by eleven other national

rehabilitation professional organizations.

The uniform data set is intended to be an appropriate, quickly administered, valid, and reliable measure which is discipline-free and acceptable to clinicians in the field. Data collected on key patient functional attributes (using the 7-level Functional Independence Measure or FIM) in a consistent manner allows clinicians and researchers to track patients from the initiation of hospital care through discharge and follow-up. With periodic reassess-

ment, changes in patient performance over time can be measured and rehabilitation outcomes determined. The uniform data set is a useful tool to facilitate treatment management and monitoring, quality assurance, program evaluation, determination of cost effectiveness of processes and resources used, and care policy decision-making.

Progress—The development of the data system has been carried out in three phases: pilot, trial, and implementation. The purpose of the pilot was to field test the instrument to determine its face validity and ease of administration. Upon completion of the pilot in the Spring of 1985, modifications were made in the instrument. The intent of the trial phase, completed in Spring 1986, and the implementation phase, begun in mid-1986 and continuing, was to assess interrater reliability, validity, precision, and time to administer the data set. Data were obtained at admission, discharge, and when feasible, follow-up 3-6 months after discharge.

Preliminary Results—Two hundred fifty patients from 25 inpatient facilities were assessed and 891 clinician assessments were performed during the trial phase. The clinicians were physicians (17 percent), occupational and physical therapists (28 percent each), and registered nurses (27 percent). Interrater reliability of the FIM was evaluated by comparing the results of multiple pairs of clinicians of differing disciplines, each pair assessing the same patient. The trial total score FIM intraclass correlation (ANOVA) was 0.88 on discharge (based on 184 observer pairs). Implementation phase preliminary intraclass correlation was 0.92 (based on 108 observer pairs). These reflect good interrater agreement.

Face validity was evaluated by means of specific

questions regarding difficulty (88 percent did not have difficulty), unnecessary items (97 percent felt there were no unnecessary items), items which should be added (83 percent felt no need for more items), and open-ended comments. The average score on an evaluation item regarding adequacy of the FIM as a measure of severity of disability was 3.4 (trial) and 3.5 (implementation) on a 5-point scale, which is in the better than average range.

Determination of the precision of the instrument (that is, how small a change is detectable from admission to discharge) revealed significant differences in trial FIM scores (10.7 ± 0.9 [standard error] FIM units). This finding suggests that the FIM has adequate precision. The time required to learn to use the FIM (60 minutes) and to routinely administer the FIM (26 minutes) seems acceptable.

Future Plans—Facilities wishing to participate in the use of the Uniform Data System will receive a GUIDE and an IBM compatible floppy diskette suitable for inputting data. Data may be forwarded to the Data Management Service (DMS) at the Buffalo General Hospital for entry into the data system, for analysis, and report back to participants.

Publications Resulting from This Research

A Uniform National Data System for Medical Rehabilitation. Hamilton BB, Granger CV, Sherwin FS, Zielezny M, Tashman JS, *Rehabilitation Outcomes: Analysis and Measurement*, M.J. Fuhrer (Ed.), Brookes, Baltimore, MD, 1987.

The Functional Independence Measure: A New Tool for Rehabilitation. Keith RA, Granger CV, Hamilton BB, Sherwin FS, *Advances in Clinical Rehabilitation* 1:6-18, M.G. Eisenberg and R.C. Grzesiak (Eds.), New York, NY, Springer, 1987.

Advances in Functional Assessment for Medical Rehabilitation. Granger CV, Hamilton BB, Keith RA, Zielezny M, Sherwin FS, *Topics in Geriatric Rehabilitation* 1(3):59-74, 1986.

Predictive Assessment in Prescription of Functional Aids for the Motor Disabled

Michael J. Rosen, Ph.D.

Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—The goal of this project continues to be the development of data, methods, and theory on which to base prediction of functional gain from therapies and technological intervention. It was

originally proposed that this concept be applied to three handicapping conditions: 1) disabling tremor of the upper limbs; 2) "equinus" and other spastic gait abnormalities; and, 3) loss of vocal communi-

cation due to impaired articulatory motor control.

Progress—During the past year, the second area has been inactive while considerable progress has been made in the first. In addition, supplementary support has been provided via this project for completing the development of the Tufts-MIT Prescription Guide, a computer-based system for optimal selection of nonvocal communication devices, funded primarily by a contract awarded to New England Medical Center Hospitals by the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS). A summary of that work may be found elsewhere in this volume.

The primary focus in the area of tremor during the past year has been the completion of a two-degrees-of-freedom manipulandum, designed and built by doctoral candidate Bernard Adelstein. This apparatus has the configuration of a joystick coupled in each of its degrees of freedom to a pancake armature DC motor. The coupling is accomplished via a novel gimbal mechanism, in effect a direct drive "two-roll wrist." This gives the manipulandum its essential back-drivable characteristic and minimizes friction and eliminates backlash. A digitally supervised analog control scheme allows the perceived impedance of the manipulandum to be varied over a broad range of experimentally interesting and/or hypothetically tremor-suppressing functions.

The motors are capable of producing 27 N force at the grip end of the handle, whose travel is about ± 10 cm in any direction and whose mechanical bandwidth is 65 Hz. Feedback of angular position, velocity, and acceleration for each degree of freedom is provided by optical encoders, tachometers, and accelerometers, respectively. The load presented to

the subject's hand at the handle grip is a function of the gains of the feedback paths that are set via multiplying D/A converters by the host computer. A two-axis force transducer mounted in the grip senses hand force. A high forward path gain between the sensor and motor output torque tends to make the undesirable torques become imperceptibly small due to friction and the small cross-coupling between degrees of freedom.

At this writing, power-on testing of the manipulandum has been under way for several months. Elastic, viscous, and inertial loads have been successfully simulated. Near elimination of friction by torque feed-forward has been demonstrated by observing that the handle will fall to the limit of its travel from any off-center position under its own weight—a characteristic very different from its power-off behavior.

Future Plans/Implications—The experiments planned for manipulandum are meant to serve two purposes. Empirical results demonstrating consistent superiority of a particular loading scheme in selective suppression of a particular tremor type will provide a basis for design of practical compliant orthoses for people disabled by that tremor. Further, even if generalizations concerning effective loads cannot be found, the manipulandum may be viewed—along with the single analysis package developed for this work—as the prototype of a clinical assessment and prescription tool. Viewed as a multi-degrees-of-freedom controllable "Cybex" machine, it could provide a means for establishing for an individual client the optimal loading scheme for selective tremor suppression.

Prospective Study of Factors in Back Pain Disability

Stanley J. Bigos

University of Washington, Health Sciences Building, Seattle, WA 98195

Sponsor: *National Institutes of Health*

Purpose—This application requests funding to identify risk factors for chronic back pain disability. The proposed study will draw on our existing database of physical, psychological, and work-related pre-morbid data. This database is unequalled in population size and scope of independent variables.

Furthermore, this study will provide the longest follow-up of any such study to date. A better understanding of risk factors would provide a solid foundation for establishing appropriate programs to prevent chronic back pain disability, to enhance return to work, and to reduce the impact back pain

has on the industrialized nations of the world. Our goal is to continue monitoring our subject population of 3,020 individuals so that risk factors for the development of chronic back pain disability can be identified.

Our efforts to establish this database have been supported to date by NIOSH; however, NIOSH has stated that the evaluation of chronic disability is beyond their scope of interest and has limited our funding to analysis for the prediction of acute industrial back injuries. To stop without evaluating chronic back pain disability would ignore the 10 percent of back injuries that cause the most suffering and account for approximately 80 percent of the total cost for back problems.

Progress—We have already found that the first 26 subjects who developed disabling back problems of at least a 3-month duration have a significantly different fitness level than their age-matched controls. With two more years of follow-up we estimate another 15 to 21 subjects will develop chronic back pain disability. An increased number of subjects in the chronically disabled category would add to the statistical power for the evaluation of other variables.

Preliminary Results—Our results to date indicate that it is highly probable that analysis of premorbid data can predict chronic back pain disability and greatly increase our understanding of this expensive healthcare problem.

Regaining Functional Abilities after Hip Fracture

Margaret A. Williams

University of Wisconsin, Madison, WI 53792

Sponsor: National Institutes of Health

Purpose—The objective of this study is to determine patterns in and factors influencing older persons' return of prior functional abilities following hip fracture. The results are anticipated to be a base for design of nursing interventions/programs/discharge plans that assist patients and families cope with this disabling event.

Specific aims are to examine: 1) patterns in resumption of activities of daily living (ADL), mobility, instrumental activities of daily living (IADL), and perceived return to normal in persons discharged to their own homes and to nursing homes; 2) the relevance to post-hospital progress of certain prior conditions and events, psychological states and perceived readiness for discharge of patients and their actual and potential family caregivers; 3) problematic aspects of the recovery period; and, 4) the congruence of patients' and caregivers' expectations of progress with actual progress.

The design is prospective and descriptive, with data collection by interview at four points: pre-hospital discharge, 2, 8, and 14 weeks post-discharge. The main sample will be 120 white female

patients age 60 and over admitted from home who have undergone surgical repair of a hip fracture and approximately 100-120 family members designated as caretakers after home discharge or temporary nursing home placement. A small comparison group of 20 male patients and their caregivers also will be followed.

Patients will be drawn from orthopedic units in three community hospitals. Instruments are the ADL/Mobility and IADL Scales, and Activity Index (perceived return to normal), a short form of the Profile of Mood States, and parallel forms of Readiness for Discharge and Symptom Distress Congruency Scales. Additional patient data will be drawn from hospital records. Data analysis will include repeated measures analysis of variance with different grouping and control factors to address patterns in the resumption of activities, multiple regression, and possibly time series analysis to address influence of independent variables, and correlations to examine relationships of mood states and incongruent expectations with progress in recovery.

Gross Motor Attainments in Eleven to Fourteen-Year-Old Children with Down's Syndrome

Alice Shea, Ph.D.

Children's Hospital, Boston, and NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *NeuroMuscular Research Center*

Progress—Data collection for this study was completed during the preceding year. Sixty-two children with Down's Syndrome were seen in addition to 20 of their normal siblings. Thirteen other children with Down's Syndrome were seen at their homes. These children were part of an original group of 89 children with Down's Syndrome who were followed for the first 3 years at the Developmental Evaluation Clinic of Children's Hospital in Boston.

Data have been analyzed on the first two segments of the study. Gross motor test results using the Peabody Scales indicated that the best performance of the children was in ball play. Their area of greatest

difficulty was static and dynamic balance. The analysis of height, weight, and maturational data suggests little or no relationship of any of these factors to motor performance.

The next part of the analysis will examine the relationship of early motor milestones in Down's Syndrome to later motor performance. This will be followed by an evaluation of the relationship of postural sway to clinical measures of balance using stabilogram measurements. This study should lead to a better understanding of motor behavior in individuals with Down's Syndrome, one of the leading causes of mental retardation.

Orthokinetic Orthoses: Clinical Efficacy Study in Non-Drug Analgesia of Post-Trauma Chronic Pain

Renate L. Neeman, Ph.D., O.T.R., F.A.O.T.A.; Diane M. Costanzo, R.P.T.; Judith E. Cline, Dip.(O.&P.T.); Mo Neeman, Ph.D.

The Center for Orthokinetics Research and Education, Williamsville, NY 14221 and Western New York Burn Treatment Center, Sheehan Memorial Hospital, Buffalo, NY 14203

Sponsor: *Orthokinetics Research Foundation*

Purpose—The purpose of this study was to investigate the clinical efficacy of orthokinetics treatment by application of orthokinetic orthoses (cuffs) to the upper extremities of patients with chronic pain secondary to: 1) tendonitis of occupational origin; 2) lateral epicondylitis due to cumulative trauma disorder; and 3) medial epicondylitis ("golfer's elbow"). The orthokinetic orthosis was designed and fabricated from spandex-reinforced elastic roller bandage material.

Progress—The three subjects had severe, disabling, chronic pain which was not mitigated by alternative treatments: massage, analgesic or anti-inflammatory medication, gentle stretching, icing, and ultrasound. The range of time since onset was 6 months to 5 years. The orthokinesis analgesia treatments comprised single-subject time-series designs, consisting of orthokinetics treatment phases with application of orthokinetic orthoses to the upper extremities,

interspersed with nontreatment negative control phases, and placebo-sham treatment positive control phases. The patients were treated in occupational or physiotherapy clinics, then instructed on proper wearing of their orthokinetic orthoses for continued analgesia during activities of daily living, work, and avocation. Their progress was followed for up to 2 years after orthokinetics treatment for analgesia. The criterion measure was Present Pain Intensity (PPI) based on the McGill Pain Questionnaire.

Results—1) The patient was a 26-year-old female physical therapist with disabling chronic pain secondary to tendonitis of the left forearm refractory to massage therapy and analgesic cream application. Orthokinetic orthoses were fabricated and applied to the left proximal forearm and wrist. The time-series consisted of phases: nontreatment (negative control A1, 2 min, PPI = 3); sham treatment (positive control C, PPI = 3); orthokinetics treat-

ment (B1, 2 min, complete temporary analgesia, PPI = 0); second nontreatment (negative control A2, 5 min, reversal of analgesia, PPI = 3); second orthokinetics treatment (B2, 3 hours with work as a physical therapist involving strenuous muscle activity, e.g., patient lifting, complete and irreversible analgesia, PPI = 0). The patient has remained free of pain for two years. The orthokinetics treatment time-series was A1-C-B1-A2-B2, administered to the patient single blind, and the resulting analgesia supported internal validity and clinical efficacy of the orthokinetic orthosis application.

2) The patient was a 56-year-old man with severe chronic pain of left elbow, forearm and wrist, secondary to left lateral epicondylitis due to cumulative trauma disorder, sustained during two decades of employment as a metal worker in the automotive industry, with heavy repetitive muscular exertion of the upper extremities. His disabling pain was refractory to physical therapy by icing, ultrasound, and gentle stretch. He was treated by application of orthokinetic cuffs to forearm and wrist. In the nontreatment phase (A1, 30 sec, PPI = 4) pain was severe. In the orthokinetics treatment phase (B1, 30 sec, PPI = 2) partial analgesia was achieved, with reversal in the following nontreatment (A2, 30 sec, PPI = 4) and placebo treatment (C, 30 sec, PPI = 3) phases. In the second orthokinetics treatment phase (B2, 30 sec, PPI = 2), partial analgesia was replicated. The patient was instructed on correct application of the orthokinetic orthoses (cuffs) during unsupervised purposeful activities of daily living; he was seen again two weeks later, when he presented in the physiotherapy clinic without pain, and his attending physician accordingly cancelled contemplated treatment by anti-inflammatory steroid injection for pain mitigation. The orthokinetics treatment time-series was A1-B1-A2-C-B2, administered to the patient single blind, and the resulting analgesia supported internal validity and clinical efficacy of the orthokinetic orthosis application.

3) The patient was a 33-year-old man with chronic pain secondary to medial epicondylitis due to a blow

to the right medial epicondyle three months prior to presenting at the occupational therapy clinic. His treatment consisted of a time-series A1-C1-A2-C2-A3-B1-A4-B2, in which the orthokinetics treatment phases B1 and B2 comprised application of three orthokinetic orthoses to the right arm, forearm, and wrist. The results were: in control phases A1, C1, A2, C2, A3 (1 min, PPI = 3), pain was unmitigated. In orthokinetics treatment phase B1 (1 min, PPI = 0), complete temporary analgesia was achieved; in the nontreatment phase A4, gradual reversal of the analgesia occurred (40 min, PPI = 0 - 3); and in the second orthokinetics treatment phase B2, complete orthokinesis analgesia was replicated (1 min, PPI = 0). The single blind orthokinetics treatment outcomes supported internal validity of orthokinesis analgesia.

Future Plans—Currently, plans for the project include exploration of clinical efficacy of orthokinesis analgesia in osteoarthritis, and chronic pain secondary to athletic injuries of the upper and lower extremities. Projected plans include a long-term cooperative clinical trial on the generalizability (external validity) of the application of orthokinetic orthoses in disabling conditions with chronic pain, as well as a long range basic research study plan concerned with testing of a proposed neurophysiological mechanism of orthokinesis analgesia. This proposal invoked stimulation by orthokinetic orthoses of cutaneous non-nociceptors, with resulting analgesia through inhibition of dorsal horn nociceptors by an enkephalinergic interneural mechanism, which will be tested utilizing the opiate antagonist naloxone for blocking enkephalin from access to its receptor.

Publications Resulting from This Research

Rehabilitation of Chronic Upper Extremity Pain in Post-CVA Hemiparesis; Tendonitis; and Lateral Epicondylitis by Orthokinesis Analgesia. Neeman RL, Costanzo DM, Cline JE, Neeman M, *Canadian Journal of Rehabilitation* 1(1):17-28, September 1987.

The Quantitative Assessment of Knee Orthoses for Control of Ligamentous Instability

A.B. Liggins, M.Sc., and P. Bowker, Ph.D.

Department of Orthopaedic Mechanics, University of Salford, Salford M5 4WT, UK

Sponsor: Science and Engineering Research Council

Purpose—The object of this project is to quantitatively assess the effectiveness of some of the knee orthoses commonly prescribed for ligamentous injuries and to identify the components of brace design which cause them to act as they do. Using this information, it is hoped to optimize the design of braces prescribed for knees with particular types of instability. It will be interesting to compare these results with the current thinking on brace design.

Progress—The braces being tested include all the commonly used types from simple knee sleeve, through “sports” braces to the “cage” type. The stiffness characteristics of each brace across a joint space are first determined statically by placing it on a model leg consisting of solid calf and thigh sections split at the joint space. The thigh section is constrained, while the calf section can be loaded in such a way as to produce anterior/posterior, medial/lateral, internal/external and valgus/varus loading on the calf section of the brace being tested. This gives the across-joint stiffness of a brace; any deviations from these values while in normal use being attributable to the effective degree of fixation

between brace and bones via the soft tissues.

The braces are then tested dynamically, using an electrogoniometer system which measures the three rotational and three translational motions of the tibia relative to the femur. The goniometer system is designed to be attached to the patient’s leg around the brace so that the two systems do not interfere with each other.

Preliminary Results—The patient is first tested without a brace to obtain a gait pattern for each leg. Comparison of these two then gives the instability artifacts on the pattern of the pathological knee which should be reduced by any effective brace. The gait patterns are then recorded for the pathological knee while using different braces. The degree of effectiveness of each brace is indicated by the reduction in instability artifacts.

In addition, if the brace acts contrary to its theoretical behavior, exhibiting a greater or lesser stiffness than expected in a certain direction, then deductions can be made regarding the efficiency of the fixation between the brace and the underlying skeletal structures.

A Survey of the Current Clinical Use of Gait Analysis in the UK

N. Messenger, B.Sc., and P. Bowker, Ph.D.

Department of Orthopaedic Mechanics, University of Salford, Salford M5 4WT, UK

Sponsor: Science and Engineering Research Council

Purpose—The principal purpose of this study was to determine the nature and extent of the current clinical usage of the numerous gait analysis and assessment centers in the UK. In addition, a database of the gait centers capable of and willing to provide a clinical service was to be compiled. This would include a profile of each center in terms of equipment available and current areas of specific interests and expertise. Finally, the opinions of the principal workers in the field as to the current status, and future potential, of gait analysis and assessment, were to be canvassed.

Progress—A postal questionnaire was devised, consisting of four basic sections: 1) equipment available; 2) current research interests; 3) clinical service commitments; and, 4) the subjective views of the respondents. This was circulated to 35 centers in both clinical and academic establishments, with known past or current interest in gait analysis and assessment. A total of 25 responses have been received, of which nine stated no current commitment to gait analysis.

Preliminary Results—The survey has provided use-

ful data on the equipment and facilities available in each center, together with details of the service available to prospective referring clinicians, and this data is being incorporated into an updatable database which it is hoped to make more widely available.

The respondents generally felt that gait analysis techniques have a clinical context, if not yet routinely, but the number of referrals to the centers, especially when taken in conjunction with the broad spectrum of pathology types being seen, is still quite small. Of the centers responding with a current interest in gait studies, ten were involved in some clinical work, though only six were seeing more than five patients per month. In recognition of this, a number of areas worthy of further work were identified by the respondents, including work on the methods of data presentation and on the education of the general clinical community. It was also recognized that greater dialogue is required both be-

tween the centers involved in gait analysis and assessment, and with clinicians, in order to more clearly define realistic objectives.

Future Plans/Implications—It is planned to repeat this project at regular intervals, to allow the progress and development of gait analysis and assessment techniques in the clinical environment to be closely monitored, both to stimulate the necessary dialogue between centers and to help in identifying any major areas of concern. In addition, it is hoped that the database of gait analysis centers will be regularly updated and made available to interested parties. A collaborative project to this end with other workers in this field is in the process of development.

The data resulting from this study have been presented at a conference and are in the process of publication.

Anterior versus Posterior Walkers for Children with Cerebral Palsy: A Gait Analysis Study

Lynne Logan, M.A., P.T.; Kathleen Byers-Hinkley, M.S., P.T.; Charles Ciccone, Ph.D., P.T.
Special Children's Center, Inc., Ithaca, NY 14850

Sponsor: *Special Children's Center, Inc.*

Purpose—Posterior walkers are becoming the support of choice for children with cerebral palsy. Their proponents claim more upright and safer ambulation. Our research team attempted to explain this clinical observation by comparing gait studies of seven children.

Progress—We used one style of anterior and one style of posterior walker. Each child walked with each type of walker. Assignment of order was random. Children were filmed with high-speed motion picture film (60 frames/second). Results were obtained by use of a Vanguard Motion Analyzer. Key points of hip flexion, knee flexion, trunk flexion, and ankle flexion were compared. Stick figures were created for key points of the gait cycle. Data for each subject was compared for each condition.

Preliminary Results—Results demonstrated that the posterior walker resulted in decreased hip and trunk flexion or a more upright posture. Knee flexion was

decreased at heel strike and midstance. Decreased double support time was also significant. Statistical significance was determined by a paired T test with significance less than 0.05. Pediatric clinicians have begun using posterior walkers and have judged that they allow clients to be more upright, therefore safer while walking. Our study provides a beginning objective confirmation of this clinical judgment. Decreased hip, trunk and knee flexion at midstance indicates a more upright posture. Decreased double support time indicates improved stability allowing more complete weight shift. This study offers biomechanical rationale for the choice of posterior walker for children with cerebral palsy.

Future Plans/Implications—We are currently adding more subjects to our study as well as looking at differences between two- and four-wheeled walkers. We presented this information in a poster format at the National APTA conference in San Antonio, Texas in June 1987.

IX. Biomechanics

A. Bone and Joint Studies

Relation of Computerized Axial Tomography (CAT) Scan Mineral Density to Mechanical Properties of Vertebrae

D.M. Donovan, B.S.; D.J. Adams, B.S.; D.D. Moyle, Ph.D.; E.W. Berg, M.D.; N. DeTorie, Ph.D.; A.T. Gilpin, M.D.; N.J. Pappas, Jr., M.D.; J.C. Reynolds, M.D.; M. Tkacik, M.S.; R.L. Waldron, II, M.D. Bioengineering Alliance of South Carolina, Clemson University, Clemson, SC 29634; William Jennings Bryan Dorn Veterans Administration, Columbia, SC 29203; and University of South Carolina School of Medicine, Columbia, SC 29208

Sponsor: VA Rehabilitation Research and Development Service and Bioengineering Alliance of South Carolina

Purpose—Previous investigations in our laboratory have studied the correlation between the mechanical properties of vertebral trabecular bone and CAT mineral density measurements and these investigations have shown a high degree of correlation between physically measured parameters and CAT data. The data have not indicated any variation in bone properties with location in the vertebral body. This finding is at variance with the data from at least one other study. The purpose of the present study was to examine the failure modes of vertebral bodies when crushed in a physiologic manner and to correlate the failure data with CAT measurements and with histomorphometric and physical property data.

Progress—Vertebral bodies were obtained during routine autopsy at Richland Memorial Hospital and at the Dorn Veterans Administration Medical Center, Columbia, South Carolina. Relevant clinical data such as age, sex, cause of death, radiological and hematological findings, etc. were recorded. As soon as possible after removal, they were radiologically evaluated by CAT scan. Three cylindrical areas within each vertebra were selected for CAT equivalent bone mineral density measurement. Following the radiologic examination, the specimens

were frozen at -20 degrees Celsius and held for subsequent mechanical testing.

The mechanical test involves crushing a vertebral body (with posterior elements removed) between “discs” made of silicone rubber in a compression fixture. Measured mechanical properties included load-to-failure and strength. Following the mechanical testing, selected portions of the specimen were embedded, sectioned, stained, and evaluated histomorphometrically. Finally, selected portions of the specimen were used for determination of calcium content by atomic absorption spectrophotometry for direct comparison of bone mineral density with the equivalent bone mineral content as determined by the CAT scan.

Preliminary Results—As of this date only ten vertebral bodies have been tested and the data are still preliminary. The results show a significant correlation between CAT measured equivalent mineral density, averaged for the whole vertebral body, and breaking load ($R = 0.75$, $n = 10$, $p < 0.03$), between the averaged CAT mineral density and the breaking stress ($R = 0.81$, $n = 10$, $p < 0.02$). The calcium content data and the histomorphometric data are in process.

Prediction of Trabecular Bone Strength and Modulus by Computerized Axial Tomography (CAT)

S.M. Lang, M.S.; D.D. Moyle, Ph.D.; E.W. Berg, M.D.; N. DeTorie, Ph.D.; A.T. Gilpin, M.D.; N.J. Pappas, Jr., M.D.; J.C. Reynolds, M.D.; M. Tkacik, M.S.; R.L. Waldron, II, M.D.

Bioengineering Alliance of South Carolina, Clemson University, Clemson, SC 29634 and William Jennings Bryan Dorn Veterans Administration, Columbia, SC 29203

Sponsor: VA Rehabilitation Research and Development Service and Bioengineering Alliance of South Carolina

Purpose—A primary clinical problem which exists today involves the early detection and diagnosis of osteoporosis. Current radiographic techniques have been shown to be relatively insensitive to the degree of skeletal mass loss and no correlations with mechanical properties have been found. The primary objectives of this research were to obtain vertebral bodies at autopsy from normal and osteoporotic individuals, to determine the compressive strength and modulus of the vertebral trabecular bone by mechanical testing, and to correlate the observed mechanical properties primarily with CAT mineral density, but also with calcium content and histomorphometric measurements.

Progress—Vertebral bodies were obtained during routine autopsy and radiographically evaluated by CAT scan. Mechanical properties of vertebral trabecular bone were determined by testing cylindrical bone specimens in simple compression to failure.

Ultimate strength and elastic modulus were determined directly from load-deformation curves. Atomic absorption spectrophotometry was used to determine weight percent calcium of each specimen, and quantitative light microscopy was used to determine area fraction bone.

Results—Significant positive correlations were found to exist between the observed trabecular bone mechanical properties and CAT mineral density. Compressive strength was correlated with both the CAT value ($r = 0.720$, $p < 0.001$) and the squared CAT value ($r = 0.755$, $p < 0.001$). Bone elastic modulus was correlated with both the CAT value ($r = 0.574$, $p < 0.001$) and the cubed CAT value ($r = 0.601$, $p < 0.001$). Trabecular calcium density was also correlated with the CAT value ($r = 0.780$, $p < 0.001$). In addition, a significant positive correlation was found between the CAT value and the area fraction bone ($r = 0.579$, $p < 0.001$).

Biomechanical Modeling of the Lower Back

Kurukundi R. Murthy, B.S., and Zvi Ladin, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: VA Rehabilitation Research and Development Service

Purpose—A computer model of the lower back musculature is currently under development and will be used to predict the distribution of muscle forces at different levels of the lumbar region under different loading conditions. The biomechanical model is being developed as part of a major research project aimed at studying lower back pain. The

project will integrate the biomechanical model described above with myoelectric signal measurement from low-back muscle into a coherent diagnosis of individual muscle dysfunction. The model will also be used to suggest isometric exercises that could selectively activate (or relieve) the affected muscles.

Dynamic Biomechanics of Spinal Implants

Richard J. Nasca, M.D.; Jack E. Lemons, Ph.D.; John H. Walker, M.D.
Veterans Administration Medical Center, Birmingham, AL 35233

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Cyclic, nondestructive, multidirectional testing of three spinal implant systems applied to swine spines and subjected to “physiologic” forces of human magnitude is reported. The ultimate aim and goal is to establish a relative database for comparative *in vitro* testing of spinal implants in current use and develop safer and more biomechanically sound spinal instrumentation.

Progress—During the 1986-1987 year, ten swine spines were instrumented with Harrington, Luque, and Drummond implants. Spines were kept hydrated while being tested in a custom-designed, pneumatic powered machine constructed for multidirectional, nondestructive cyclic testing of intact animal and human spines. A thirteen segment spine length extending from T7-L4 was used. The terminal vertebrae were mounted in acrylic in aluminum cups machined for attachment to the upper and lower platins of the machine. Each spine was tested without instrumentation (control), then with a single Harrington distraction rod, paired Luque rods, and Drummond rods. 1677 Newtons (377 pounds) compression and 15 Newton-meters (445 pounds-inch) torsion was simultaneously applied via pneumatic cylinders. The maximum excursion of the axial compression cylinder was set at 1.3 centimeters. Maximum angular displacement of the torsion cylinders was 15 degrees in a clockwise and counterclockwise direction. Off-axis tests were set with the spine positioned at 6 degrees off the vertical neutral axis. Spines were preconditioned for each loading mode to allow for equilibration of the systems, relaxation and warm-up conditioning of the tissues. Radiographs were taken before, during, and after testing. Angular and linear displacements were determined using a photographic method. These spines were also videotaped in the posterior-anterior and lateral projections. A triaxial reference device consisting of three 10 centimeter rods attached to a middle thoracic, lower thoracic, and upper lumbar spinous process was utilized as orthogonal points of reference. These triaxial devices were referenced to 90 degree camera positions and fixed points on

the machine. These nine orthogonal points were digitized using the photographs taken in the posterior-anterior and lateral projections. Digitized points were analyzed by a dedicated computer using kinematic techniques. Statistical analysis of the data was then carried out by the Department of Biostatistics.

Preliminary Results—Angular and linear displacement data generated during the multiaxis cyclic testing showed that the Drummond and Luque systems were equally resistive to axial compression forces applied to the vertically placed spine and implant systems. Off-axis compression with the spine oriented 6 degrees off the vertical again showed the Luque and Drummond systems to be more stable in lateral bending and angular displacement than the single Harrington distraction rod. The Drummond system appeared slightly more rigid than the Luque rods but this was not statistically significant. During axial torsion at 15 degrees in each direction there was no wire breakage, hook dislodgement, or cut-out. The Harrington hooks were noted to rotate and wobble at bony sites of attachment during cycling. When axial compression and torsion forces were applied simultaneously, both the Luque and Drummond systems resisted angular displacements more than the Harrington distraction rod. Linear displacement measurements revealed similar trends. During simultaneously applied off-axis compression and torsion forces, the Drummond system was slightly more resistant to angular displacement than the Luque system. The Harrington rod was most taxed during this severe testing regimen. It provided no more support than the uninstrumented spine. This was because of bowing of the rod and the relative displacement of the hooks at their insertion sites.

Future Plans/Implications—Further multidirectional cyclic testing of posterior and anterior spinal implants is planned for the coming year. Prototypes of anterior fixation devices have been prepared and

are currently in production for *in vivo* and *in vitro* testing.

Publications Resulting from This Research

Cyclic Axial Loading of Spinal Implants. Nascia RJ, Hollis JM, Lemons JE, Cool, TA, *Spine* 10:792-798, 1985.

Presentations

Biomechanical Testing of Spinal Implants, presented to the North American Spine Society, Banff, Canada, June 1987.

Biomechanical Testing of Spinal Implants, to be presented to the Federation of Spine Association, February 1988, Atlanta, Georgia.

Pathokinesiology of Anterior Cruciate Ligament Deficiency

Richard Shiavi, Ph.D.; Thomas Limbird, M.D.; Alvin Strauss, Ph.D.

Veterans Administration Medical Center, Nashville, TN 37203 and Vanderbilt University School of Engineering, Nashville, TN 37235

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objective of this project is to investigate the deviations from normal kinematics and muscle function in knees with ruptured anterior cruciate ligaments (ACL). Measurements are made using six-degree-of-freedom goniometry and electromyography during walking and pivoting.

Progress—The knee kinematics of 25 individuals with uninjured knees and of 20 individuals with injured knees have been investigated. The kinematics were quantitated using helical motion analysis. The results of the helical motion analysis reveal clearly that the knee is definitely neither a hinge nor a planar joint. It is a dynamic joint whose kinematic behavior changes over the stride. Statistical analyses were used to compare the kinematics of the injured and uninjured knees and quantitatively define the changes that occur from the loss of the anterior cruciate ligament. These changes are significant. Ligamentous loss results in more adduction and external rotation during certain periods of the stride. Also, the range of translation of the tibia in the medial/lateral direction is reduced and its mean translation is more medial.

The study of electromyogram (EMG) patterns in muscles acting around the knee joint reveals that individuals with injured knees have deviations in EMG linear envelopes with respect to the normal

population. The most significant difference during walking is that the rectus femoris no longer has peak activity during the swing to stance transition period. During pivoting, the most significant difference is that in the gastrocnemius, the amplitudes of the major and minor phases of activity are switched. Unusual phasing of the peak activity in certain muscles is consistent throughout the patient population. Increased activity of otherwise quiescent muscles during specific intervals of the gait cycle can most likely be related to the absence of the ACL and the support it would normally provide.

Future Plans/Implications—Presently the data are being analyzed to determine if there is a difference between individuals with tight and loose injured knees. Research is continuing in order to study the effect of corrective procedures and joint prostheses on knee kinematics and muscle function.

Publications Resulting from This Research

Helical Motion Analysis of the Knee—I. Methodology for Studying Kinematics During Locomotion. Shiavi R, Limbird T, Frazer M, Stivers K, Strauss A, Abramovitz J, *Journal of Biomechanics* 20(5):459-469, 1987.

Helical Motion Analysis of the Knee—II. Kinematics of Uninjured and Injured Knees During Walking and Pivoting. Shiavi R, Limbird T, Frazer M, Stivers K, Strauss A, Abramovitz J, *Journal of Biomechanics* 20(7):653-665, 1987.

Effect of Ligamentous Instability on Knee Joint Proprioception

Harry B. Skinner, M.D., Ph.D., and W. Dilworth Cannon, M.D.
Veterans Administration Medical Center, San Francisco, CA 94121

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is to test the hypothesis that anterior cruciate ligament injured knees have impaired proprioception perception that may contribute to accelerated deterioration of these knees.

We propose to measure proprioception in two ways. The first is to test the ability of a patient to reproduce a given position of the lower leg in space. The second is to test the patient's ability to perceive motion at the knee controlling position, velocity, acceleration, and the rate of change of acceleration (jerk).

Progress—Angular motion at the knee can be measured by measuring displacement at the ankle if the length of the leg is known. The angle is equal to 2 times the distance the angle moves, divided by the distance from the center of rotation of the knee to the ankle.

A transmitter that outputs the sound of a known wavelength and a reference light signal is placed on the ankle. The phases of the sound and light signals

can then be compared. As the ankle moves toward the receiver, the phase of the sound advances relative to the phase of the reference light signal. Using ultrasound at 40 KHz and measuring the phase to 0.05 Hz, it is possible to measure relative motion between the transmitter and receiver at 0.5mm. As most tibias are approximately 40 centimeters long, this permits measurement of motion at the knee in a noncontact fashion with an accuracy of about 0.12 degrees.

Preliminary Results—Two transmitters and two receivers, including phase comparators, counters, and position displays, are complete and working. Mechanical supports and partitions, which serve to separate the signals from the injured, and a control normal knee that serves to support the positioning motors are complete. Stepping motors which will be able to control the position of the ankle with a precision of 0.001 of an inch are purchased. The stepper motor drivers are yet to be completed.

Study of Bone Structural Response to Altered Loading

Harry B. Skinner, M.D., Ph.D.; C. Daniel Mote, Ph.D.; Jim M. Meagher, M.S.; Joyce H. Keyak
Veterans Administration Medical Center, San Francisco, CA 94121

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objective of this research is the study of mechanically-induced adaptive bone response with the focus upon development of patient-specific, analytic, predictive models and noninvasive imaging techniques. Three-dimensional finite element models automatically generated from CT scan data will be used to predict bone remodeling along principal stress directions, according to Wolff's Law. Theoretical results will be compared with actual bone remodeling obtained from histology.

Progress—A two-dimensional finite element analysis indicated core drillings in a canine femur would cause altered principal stress directions and result

in bone remodeling. Such drillings were performed and the results were monitored for nine months with CT scans. Histology of the retrieved hips will establish the actual remodeling and permit verification of our finite element predictions as well as our noninvasive histomorphometry technique.

To determine the three-dimensional *in vivo* stress distribution, digital image processing software was developed. The software automatically extracts bone geometry, density, and microstructural orientation from the serial CT scan. To create the finite element model, eight-noded "brick" elements are automatically generated according to the bone geometry. Mesh density is user-specified. The elastic modulus

is variable throughout the model and is determined by using quantitative computed tomography and a density-modulus relationship. Inclusion of microstructural orientation in the model is under investigation.

In vitro evaluation of bone contour extraction and microstructural identification software were tested using an excised vertebra. Trabecular spacing, area fraction of bone, and orientation angle were calculated using thresholded CT scans and CT images enhanced with software developed as part of this study.

Results—Densification of cancellous bone surrounding the core drillings is apparent. Quantitative verification of finite element model predictions await histologic sectioning now being performed. Comparison of image processing results for the vertebrae

with calculations made from histologic sections verifies that the enhanced imaging is less sensitive to display setting than thresholding; and significantly improves the accuracy of calculated trabecular spacing and area fraction of bone. Preliminary inspection of the automated finite element analysis indicates qualitative results consistent with previous finite element models generated by hand. Further analysis and testing is necessary for verification of quantitative results.

Future Plans/Implications—Results of this study will be applied to study patient-specific fracture risk and prosthesis design. The automated finite element modeling technique also can be adapted to model other tissues and objects which can undergo CT scanning.

Bone In Vivo and In Vitro Stress and Strain Patterns

Dan M. Spengler, M.D. and Tony S. Keller, M.S.E.

Department of Orthopaedics and Rehabilitation, School of Medicine, Vanderbilt University, Nashville, TN 37232

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objective of this research was two-fold: to test the hypothesis that “bone models/remodels during growth and altered activity in order to maintain an optimal state of strain,” and to determine the level of activity necessary to maintain or augment normal bone strength.

Progress—Immature (3- to 17-week-old) and adult rats were subjected to normal, hypoactivity (bedrest, paralysis, simulated weightlessness) and hyperactivity (voluntary and involuntary exercise) regimens. Bone stress and strain patterns were recorded from the femur at mid-diaphysis *in vivo* (gait) and *in vitro* (static and dynamic mechanical tests). Histomorphometric and biochemical analyses of the femur cross section were also conducted.

Results—In the normal rat, a two-fold increase in both bone geometric and material properties resulted in a four-fold increase in bone structural properties (strength) during growth, which was followed by a greatly reduced rate of change in the adult. No changes in the *in vivo* strain, stress or resultant moments were observed during growth or in the

adult and the ratio of torsional strength to *in vivo* load (torsional safety factor, ST) remained constant (ST=12). Hypoactivity resulted in a significant reduction in bone geometry, which was partially compensated by an increase in bone calcium content, but overall the bone strength was significantly reduced. Hyperactivity (0.02 to 4.0 kilometers/day running at 11.2 meters/minute), however, did not significantly alter bone geometric, material or structural properties beyond that of normal growth. An activity “window,” therefore, is hypothesized to exist below which reduction in bone properties occurs and above which an increase in bone properties is predicted to result. The loads imposed by moderate activity (running at 11.2 meters/minute, 0.005 peak strain/second) do not appear to augment bone geometry, material or structure.

Future Plans—Our plans for the immediate future are to correlate the appendicular bone mineral content (BMC) in athletes to level of activity. Three groups of athletes will be examined: 1) high intensity, short duration (weight lifting); 2) medium intensity, medium duration (sprinting); and, 3) low intensity,

long duration (running). The BMC will be correlated to the workout intensity in order to identify the load threshold necessary to stimulate a positive osteogenic response. In addition, we are planning to examine the normal and pathogenic response of the lumbar spine to vibration and other loading modes in an effort to assess mechanical factors involved in low back pain.

Publications and Awards Resulting from This Research

Fatigue of Immature Baboon Cortical Bone. Keller TS, Lovin JD, Spengler DM, Carter DR, *J. Biomechanics* 18:297-304, 1985.

Geometric, Elastic, and Structural Properties of Maturing Rat Femora. Keller TS, Spengler DM, Carter DR, *Journal of*

Orthopaedic Research 4:57-67, 1986.

The Effects of Simulated Weightlessness on Bone Biomechanical and Biochemical Properties in the Maturing Rat. Abram AC, Keller TS, Spengler DM, *J. Biomechanics*, (in press).

Biomechanical Response of Immature Bone During Voluntary Exercise. Keller TS, Harris NL, Spengler DM, *Calcif. Tissue International*, (in press).

Regulation of Bone Stress and Strain in the Immature and Mature Rat Femur. Keller TS, Spengler DM, *J. Biomechanics*, (in press).

1986 National Student Research Forum Physical Medicine and Rehabilitation- Education and Research Foundation Award in Physical Medicine and Rehabilitation, A.C. Abram.

1987 National Student Research Forum Physical Medicine and Rehabilitation-Education and Research Foundation Award in Physical Medicine and Rehabilitation, N.L. Harris.

1987 American Society of Biomechanics Predoctoral Award, T.S. Keller.

Biomechanical Testing of Spinal Instrumentation Systems

Avinash Patwardhan, Ph.D.; Mark Lorenz, M.D.; Mark Sartori, B.S.

Department of Orthopaedics, Loyola University Medical Center, Maywood, IL and Rehabilitation Research and Development Center, Hines Veterans Administration Hospital, Hines, IL 60141

Sponsor: AcroMed Corporation, Cleveland, OH

Purpose—A variety of instrumentation systems are available today and new ones are being developed for the purpose of stabilizing single or multiple spinal levels in the lumbar and lumbosacral region. The primary goal of an instrumentation system used in surgical stabilization of spinal segments is to share the loads acting on the spine until a solid biologic fusion has taken place. The ability of a spinal instrumentation system to meet this goal can be evaluated by quantifying the failure load and rigidity of the construct under physiologic loading conditions. The goal of this study is to perform biomechanical evaluation of these instrumentation systems under static as well as cyclic loads.

The specific objective of the study is to perform

comparative evaluation of two instrumentation systems for single segment stabilization. These are: the Variable Screw Placement (VSP) Spine Plate, and the PDC Clamp.

Progress—The test apparatus has been fabricated and initial studies are being performed to evaluate the accuracy and reproducibility of the measurement system. Samples of the two instrumentation systems will be tested to quantify the following characteristics of each: 1) failure strength and rigidity (load-deformation characteristics) of the construct under static loading; 2) rigidity of the construct following repeated application of loading cycles; and, 3) fatigue life of the construct.

Evaluation of the Slide Board Exercise for Anterior Cruciate Ligament Rehabilitation

Lisa Vervena; J. Long; Steven I. Reger, Ph.D.

Department of Musculoskeletal Research, The Cleveland Clinic, Cleveland, OH 44106

Sponsor: The Cleveland Clinic Research Foundation

Purpose—The slide board exercise is used clinically for the rehabilitation of patients with anterior cruciate ligament (ACL) reconstructions. It involves sliding side-to-side, in a speed-skating motion, over

a low-friction surface. This weightbearing exercise may avoid the impact loading of walking, running, and jumping rope. It enforces co-contraction of the quadriceps and hamstrings in a safe range of motion

of the knee, and should improve balance and coordination. Properly designed, the portable slide board platform is an inexpensive device suitable for patients' use at home. The goal of this study is to assess the potential for injury from varus or valgus moments on the collateral ligaments of the knee at push-off from, or collision with, the slide board bumpers.

Progress—A slide board has been constructed on a wooden platform using a 2-foot by 8-foot sheet of Marlite™ with padded bumpers at the ends. This slide board was instrumented with two AMTI force plates, one to measure the vertical force at the point of foot-bumper contact and the other to measure the lateral force of collision. This data is transmitted through A/D converters into a microprocessor and manipulated for immediate display, with hard copies

for permanent patient record.

Results—Data acquired in preliminary tests have shown that the vertical force exceeds body weight at contact, then decreases below body weight, while the lateral force ramps to a maximum during push-off, and then rapidly decreases to zero after separation from the bumper. EMG data verifies simultaneous contractions of the quadriceps and hamstring muscles during this exercise, lending stability to the joint and minimizing tension on the reconstructed ACL.

These test results will provide a quantitative assessment of patients' progress in rehabilitative therapy. In addition, the test results may be used to evaluate differences in velocity, stance, bracing, and training. Possible or necessary changes in the design of the exercise platform can also be evaluated.

Biomechanical Testing of a New Anterior Construct for Segmental Spinal Fusion

Avinash Patwardhan, Ph.D.; James Boscardin, M.D.; Robert Kenna; Mark Sartori, B.S.

Department of Orthopaedics, Loyola University Medical Center, Maywood, IL; Rehabilitation Research and Development Center, Hines Veterans Administration Hospital, Hines, IL 60141; Howmedica, Rutherford, NJ

Sponsor: *Howmedica*

Purpose—The use of a posterior interbody fusion is a well recognized technique in stabilizing a spinal segment in the surgical treatment of low-back pain. However, potential problems often arise in using this technique due to difficulty in incorporating bone grafts, resorption of the graft, a lack of anterior support, and potential additional morbidity in procurement of the graft. The overall purpose of this study is to evaluate the efficacy of a porous-coated insert as an anterior fusion construct for low-back pain surgery.

The specific objective of this study is to evaluate the mechanical stability of spinal segments under physiologic loads following implantation of the fusion construct in a baboon model.

Progress—To date, 11 baboon spines have had segmental destabilizations to serve as a control group for evaluation of the implant. From this group, three were used to study the installation system, and eight were retained for actual biomechanical testing of the operated segment. In addition, 12

baboon spines have had procedures performed to install the test implant in conjunction with surgical segmental destabilization. Six of these specimens have been selected for the 6 week postoperative study group, and the remaining six will be sacrificed for 12 weeks postoperatively. All baboon specimens have had anterior-posterior radiographs, and lateral radiographs in flexion and extension prior to any given procedure. Immediately postoperatively, the specimens with implants have had additional A/P and lateral X-rays taken. Lastly, prior to sacrifice, all specimens have had a final set of radiographs taken with three views, as in the initial set.

Future Plans—The next phase of this study will involve analysis of the mechanical stability of the harvested baboon specimens. This step will involve measurement of the load-deformation properties of individual spinal segments in flexion-extension, lateral bending, and torsion. These tests will be performed on specimens consisting of shams, and those with implants.

Knee Biomechanics of Athletes with High Risk Exposure to ACL Injury

M. Solomonow, Ph.D., and R. D'Ambrosia, M.D.

Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: *LSU Department of Orthopaedics*

Purpose—The objective of this study was to identify specific sports activities that may render the athlete at high risk to ACL injury, and to outline the appropriate preventive exercise to be used as an adjunct to such activity.

Progress—It was shown that athletes participating regularly in sports such as basketball, volleyball, or resistive exercises which routinely utilize the quadriceps over and above the frequency of use of the hamstrings, develop low and inhibited coactivation of the hamstrings during knee extension. This ex-

poses the joint to weakened resistance to injury. Athletes, such as triathlon participants, who utilize their hamstrings regularly, have normal coactivation of the hamstrings and thus lower exposure risk to injury.

Preliminary Results—It is suggested that athletes with muscular imbalance engage in adjunct hamstring exercise before or after their chosen sport to reduce their high risk exposure to knee ligament injuries.

Biomechanics and Electromyography of Anterior Cruciate Ligament (ACL)-Deficient Knees

M. Solomonow, Ph.D., and R. D'Ambrosia, M.D.

Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: *LSU Department of Orthopaedics*

Purpose—The objective of this study was to identify the biomechanics and electromyography patterns associated with knee instability due to ACL deficiency, and to develop a noninvasive, reliable methodology for diagnosis as well as rehabilitation modalities to be used as alternatives or adjuncts to current procedures.

Progress—Findings to date show that a reflex arc exists from ACL receptors to the hamstrings and,

upon overloading of the ligament, the arc is triggered on to provide muscular assistance in preventing damage to the ligament. Furthermore, in the absence of the ACL due to trauma, receptors from the joint capsule or muscles perform the same function such that joint stability is preserved (*American Journal Sports Medicine*, May, 1987). Hamstrings exercise therapy was clearly shown to be a proper rehabilitation modality.

Quantification of Mobility Performance for Functional Assessment, Diagnosis, and Therapy of Neuromuscular, Skeletal, and Synovial Joint Dysfunctions

Robert W. Mann, Sc.D., and Derek Rowell, Ph.D.

Harvard University-Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: *National Institute on Disability and Rehabilitation Research; National Science Foundation; VA Rehabilitation Research and Development Service*

Purpose—Functional assessment of disabling mobility and manipulation pathologies requires reliable means for quantitatively documenting the kinematic and dynamic state of the movement-impaired individual. Such capability can establish the effective-

ness of surgical and/or rehabilitative procedures. This project involves an assessment process that goes beyond documenting the current status of the patient.

Computer-Aided Surgical Simulation (CASS) is a

computer-based system whose antecedent was Computer-Aided Design (CAD). These techniques, when applied to musculoskeletal defects will provide the medical practitioner with a computer-graphics display of the patient's anatomy, on which a tentative therapeutic procedure can be implemented.

When representations of the patient's musculoskeletal anatomy in the computer database are altered by the simulated intervention, the computer displays the effect on the patient's posture, mobility, joint range-of-motion, etc. The medical practitioner can then compare the original state of the movement capability of the patient, acquired via a movement analysis system, with the changes that would occur if the simulated procedure were actually performed. The physician or therapist would then be free to alter or optimize the proposed procedure until satisfied or perhaps abandon it prior to actual surgical or therapeutic intervention.

The project is subdivided into four tasks: mobility analysis; patient-specific anatomical representation; individual muscle activity determination; physician/computer interfacing.

Progress—The electro-optical camera-based, TRACK software systems at the Newman Laboratory at MIT and the Biomotion Laboratory at Massachusetts General Hospital are being used to acquire kinematic and dynamic patient data relevant to the study. The hospital location of the MGH system facilitates its primary use for patient studies while the MIT system serves as a test bed for research enhancement.

Among the clinical studies at MGH pertinent to this project, the subject with the prosthetic femoral head that senses pressure at 10 locations on her acetabular cartilage continues as a source of novel data for more than 3 years now. She is fully recovered and has a completely normal, pain-free, and functional hip. The instrumentation in the prosthesis also continues to perform flawlessly. The stabilization over time of the peak-pressure values measured during normal movement tasks is providing quantitative information on the recovery time of the musculoskeletal system following major hip surgery. Whereas pressures in normal level walking had stabilized by the end of the first year post-operatively, stair climbing data stabilization required several more months, and it was fully a year and a half before stable values occurred in the highest pressure producing movement, that of rising from

a low chair without arm assist. This new information provides, for the first time, a quantitative assessment of the mechanical state of the human hip joint during the entire process from surgery to full normal performance.

The hip pressure data, in particular the magnitude and orientation of the peak pressures during stair-climbing and rising from a chair, implicated the co-contraction of major muscle groups about the joint. The pressures measured could not otherwise be reconciled with the kinematic and dynamic analyses based on the TRACK data. To explore this hypothesis, multiple muscle EMG recording was added and synchronized with the prosthesis pressure, TRACK kinematic, and forceplate data. The new muscle information confirms the co-contraction hypothesis. Dynamic studies estimating joint forces from gait analysis records must recognize that such co-contraction augments the force the joint experiences but that cannot be discerned from the kinematic and forceplate data.

The novel pressure data from this one subject must, of course, be supplemented by information from a larger patient population. A contract from the Veterans Administration Rehabilitation Research and Development Service to the Veterans Administration Medical Center in Jamaica Plain, Boston, is supporting the assembly, test, and implantation of up to six additional pressure-instrumented prostheses. Experience with technical aspects of the first implant will influence the design of subsequent devices.

A second clinical study at the MGH Biomotion Laboratory exploited their bilateral TRACK capability in a comparison of body center-of-pressure, as measured on the two forceplates, versus determination of the body center-of-mass based on the kinematics of an 11-segment model of the human including the extremities, the trunk, and the head. The technique was developed using normal subjects and is being applied on a population of cerebral palsied children.

The research effort at MIT completed improvements in TRACK calibration techniques, axis of rotation determination, and data processing including comparisons of filtering versus smoothing, and axis-of-rotation determination. Research and development continued on the large-volume TRACK system that will provide quantitative movement information over multiple strides, during unstruc-

tured mobility such as in the simulation of electronic travel aids for visually-impaired persons, or to study the controllability of powered wheelchairs.

Patient Specific Anatomical Representation. Computer tomographic (CT) and magnetic resonance imaging (MRI) two-dimensional scan data provide quantitative information for two aspects of the computer-aided surgical simulation system.

First, dynamic force estimations using TRACK kinematic data in Newton's equations require the mass and inertial properties of the individual limb and body segments. The traditional approach of scaling such data from cadaver measurements on very limited and homogeneous populations is inappropriate here, since the system data must be specific to the particular patient whose physiognomy is frequently abnormal. Research comparing estimates of segment inertial properties computed from the scans with direct physical measurements of the same cadaver segments have confirmed the feasibility and accuracy of automatic estimation of segment parameters based on CT or MRI scans.

The CT or MRI scans are also used to generate color graphic displays of the patient's anatomy on which the simulated procedure is conducted. Major efforts this past year have focused on database design and data processing techniques to reduce computation and memory requirements necessary to construct and manipulate three-dimensional representations of anatomy generated from contiguous series of two-dimensional scans.

Individual Muscle Activity Determination. The musculoskeletal effort in support of the Computer-Aided Surgical Simulation program is now supported under a National Science Foundation grant, the progress report of which is presented elsewhere in this Journal.

Physician/Computer Interfacing. By education and experience, physicians traditionally employ visually acquired information as contrasted with the mathematical descriptions used by engineers. Since all data in the computer is number-based it must be presented to the medical practitioner in familiar visual form. Thus our computer graphics must employ and exploit, in a natural fashion, the inherent knowledge and skills of the surgeon or therapist without imposing new, additional training burdens. Although much technique can be adapted from the now well-established field of computer-aided design, including the use of graphic windows, menus, point-

ers, and cursor and mouse-control, certain aspects of graphic manipulation in surgical simulation are quite different from what is encountered in engineering design. Natural anatomical objects are far more amorphous and complex in shape than the more regular prismatic and curvilinear engineering objects. Furthermore, engineers usually develop a device *de novo*, building element upon element, whereas in surgical simulation the bone shape, for example, must be presented as it is and techniques must be developed for permitting the simulation of alteration, as for example, in intertrochanteric osteotomy. A major effort this past year has developed the data structure and graphic interactive techniques for performing such "cutting" and "glueing" techniques, simulating the severing of bone and the subsequent natural biological reconnection process.

Publications Resulting from This Research

- Determination of Body Segment Inertial Properties.** Brown GA, Tello RJ, Rowell D, Mann RW, *Proceedings, RESNA 10th Annual Conference*, San Jose, CA, 1987.
- Determination of Body Segment Parameters Using Magnetic Resonance Imaging.** Brown GA, Tello RJ, Rowell D, Mann RW, *9th Annual IEEE EMBS Conference*, Boston, MA, November 1987.
- Determination of Body Segment Parameters Using Computerized Tomography and Magnetic Resonance Imaging.** Brown GA, Tello RJ, Rowell D, Mann RW, *ASME Winter Annual Meeting*, Boston, MA, December 1987.
- A Precision PAM-FM Multichannel Implantable Patient-Monitor Telemetry System.** Burgess RG, Mann RW, *9th Annual IEEE EMBS Conference*, Boston, MA, November 1987.
- Investigation of In Vivo Loading Rate Characteristics in a Human Hip Joint.** Carlson KL, Hodge WA, Fijan RS, Mann RW, Harris WH, *Proceedings RESNA 10th Annual Conference*, San Jose, CA, 1987.
- Transmission of External Force Pulses Across the Human Hip Joint.** Carlson KL, Rogers LL, Hodge WA, Mann RW, *ASME Winter Annual Meeting*, Boston, MA, December 1987.
- Arising from a Chair: The Role of Bi-Articular Muscles in Resolving Lombard's Paradox.** Catani F, Hodge WA, Mann RW, *9th Annual IEEE EMBS Conference*, Boston, MA, November 1987.
- Hip Dynamics in Level Walking, Stair Climbing and Rising from a Chair.** Catani F, Hodge WA, Mann RW, *ASME Winter Annual Meeting*, Boston, MA, December 1987.
- The Role of Co-Contraction During Human Movement.** Catani F, Hodge WA, Mann RW, *ASME Winter Annual Meeting*, Boston, MA, December 1987.
- Estimation of Camera Positions and Orientations Using a Control Distribution of Unknown Relative Geometry.** Fijan RS, Mansfield PK, Mann RW, *ASME Winter Annual Meeting*, Boston, MA, December 1987.
- Human In Vivo Acetabular Pressure Measurement: A One-Year Update.** Hodge WA, Fijan RS, Carlson KL, Riley PO, Mann RW, Harris WH, *Transactions of the 32nd Annual Meeting of the Orth. Research Society*, 11:436, 1986.

Contact Pressures in the Human Hip Joint Measured In Vivo. Hodge WA, Fijan RS, Carlson KL, Burgess RG, Harris WH, Mann RW, *Proceedings of the National Academy of Sciences*, USA 83:2879-2883, May 1986.

Hip Dynamics in Star Climbing and Rising from a Chair Following Hip Arthroplasty. Hodge WA, Zimmerman S, Riley PO, Mann RW, *Proceedings, RESNA 10th Annual Conference*, San Jose, CA, 1987.

The Influence of Hip Arthroplasty on Stair Climbing and Rising from a Chair. Hodge WA, Zimmerman S, Riley PO, Mann RW, *ASME Winter Annual Meeting*, Boston, MA, December 1987.

Interpreting Femoral Head Pressure on Natural Acetabular Cartilage In Vivo Via Gait Analysis. Mann RW, *Proceedings, Second Annual East Coast Clinical Gait Laboratory Conference*, Philadelphia, PA, November 1986.

Rehabilitation Implications of In Vivo Hip Pressure Measurements. Mann RW, Carlson KL, Burgess RS, Fijan RW, Hodge WA, Harris WH, *Proceedings, RESNA 9th Annual Conference*, Minnesota, 201-203, June 1986.

Internal Calibration of Opto-Electronic Cameras. Mansfield PK, Fijan RS, Mann RW, *9th Annual IEEE EMBS Conference*, Boston, MA, November 1987.

Opto-Electronic Camera Image Plane Calibration. Mansfield PK, Fijan RS, Mann RW, *9th Annual IEEE EMBS Conference*, Boston, MA, November 1987.

A Comparison of Smoothing and Digital Filtering/Differentiation of Kinematic Data. Murphy M, Mann RW, *9th Annual IEEE EMBS Conference*, Boston, MA, November 1987.

Evaluation of Posture and Balance in Cerebral Palsied Children. Riley PO, Hodge WA, Gould A, Ehrlich M, Harris WH, Mann RW, *Proceedings, RESNA 10th Annual Conference*, San Jose, CA, 1987.

Center of Gravity Estimation Technique in the Study of Postural Control. Riley PO, Hodge WA, Mann RW, *ASME Winter Annual Meeting*, Boston, MA, December 1987.

Determination of Joint Centers for Posture Studies. Riley PO, Fijan RS, Hodge WA, Mann RW, *ASME Winter Annual Meeting*, Boston, MA, December 1987.

Generation of Surface Anatomy from CT MRI Images. Tello RJ, Chang G, Mann RW, Rowell D, *Proceedings, RESNA 10th Annual Conference*, San Jose, CA, 1987.

Comparison of Finite Helical Axis Estimation to Instantaneous Helical Axis from Noisy Kinematic Data. Van der Meulen MC, Murphy MC, Mann RW, *Orthopaedic Research Society Conference*, Atlanta, GA, February 1988.

Segmental Bone and Joint Replacement after Tumor Resection

Edmund Y. Chao

Mayo Foundation, Rochester, MN 55905

Sponsor: National Institutes of Health

Purpose—The emerging advances in adjuvant therapies for malignant bone and soft tissue tumors and the introduction of a surgical staging system to rationalize the extent and margin of tissue resection have renewed the interest in limb-saving procedures. The use of prosthetic implants based on the most advanced biomechanical design concepts and new implant materials appears to be very promising, not only providing useful limb function for curable cancer patients, but also as a palliative treatment benefiting those with metastatic lesions. Two systems of metallic tumor prostheses were developed, but our clinical and laboratory results have demonstrated significant residual problems associated with these devices.

The currently proposed renewal is to achieve the following specific aims: 1) to develop a new non-porous-coated modular tumor prosthetic system; 2) to modify the previous porous-coated modular prosthetic system and to examine the efficacy of extra-cortical fixation through bony ingrowth; 3) to investigate the adjuvant therapy effects on tissue incorporation into the porous implant; 4) to develop a

method to attach soft tissue to the prosthesis; 5) to correlate patients' clinical assessment results with their biomechanical functional evaluation results; and, 6) to develop booklets for better patient home care and to write instructional manuals describing surgical techniques involving these prostheses.

Bone geometric study and theoretical and experimental stress analyses will be performed to optimize the design of the modular systems. Dogs will be used as the models to investigate the biological, functional, and adjuvant therapy effects on prosthesis fixation through radiographic, histologic, and biomechanical analyses of the specimens. Established objective functional evaluation methods and techniques will be used to study the patient's functions and correlate them with the clinical assessment criteria proposed by Dr. W. Enneking. We plan to initiate a multi-institutional trial program after the new prosthetic systems are developed and tested.

The long-term objective is to perfect two segmental bone/joint prosthetic systems which can be safely used on the majority of the patients with resectable primary tumors for restoration of function and those

with metastatic lesions for palliative purposes. These devices can also be used effectively in general orthopedic surgery for limb salvage in the treatment

of trauma, infection, metabolic bone disease or failed joint arthroplasty cases with extensive bone loss.

Biomechanics of Metastatic Defects in Bone

Wilson C. Hayes

Beth Israel Hospital, Boston, MA 02215

Sponsor: National Institutes of Health

Purpose—Advances in the palliative treatment of patients with established metastatic malignancies have not only prolonged patient survival but also increased the incidence of bony metastases and subsequent pathological fractures. Thus, the prevention and effective treatment of fractures associated with metastatic defects in bone has become an increasingly important aspect of the care of cancer patients. Unfortunately, only the crudest of clinical guidelines are currently available which may be used to assess the increased fracture risk associated with metastatic lesions in bone. Therefore, the appropriate time for prophylactic stabilization of impending fractures is not known.

This investigation will be directed in the long-term to the development of comprehensive biomechanical guidelines for the orthopaedic assessment and treatment of metastatic defects in long bones, the proximal femur, and the spine. A four-phase, staged approach will be used. In Task I we will conduct retrospective radiographic reviews of pa-

tients exhibiting metastatic lesions in those regions and determine the most frequent sites and approximate shapes of the lesions. As part of this task, we will also develop improved diagnostic imaging procedures for the description of lesion geometries. In Task II, we will determine *in vitro* the strength reductions associated with simulated defects in long bones, the proximal femur and the spine. In Task III we will use finite element modeling of defects in these regions to provide a theoretical framework for interpreting the experimental results and assessing the sensitivity of the fracture risk predictors to individual patient variations. In Task IV we will combine these findings by developing structural predictors of fracture risk for individual patients with particular lesions. Biomechanical guidelines appropriate for each skeletal region will be developed and tested retrospectively in clinical populations. These guidelines should represent a significant improvement in the orthopaedic care of patients with metastatic defects in bone.

A Comprehensive, Quantitative, Predictive Model of the Human Knee Joint

Robert W. Mann, Sc.D.

Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: National Science Foundation

Purpose—The knee is the largest, most complex, and most frequently injured of the synovial joints in the human body. Subject to highly complex loading, especially in single-leg support, in athletics, and in unexpected falls, it is also susceptible to externally induced trauma due to the absence of thick, soft, surrounding tissue such as cushions the hip. Knee injuries frequently culminate in permanent debilitation and may lead to osteoarthritis and the need for consequent replacement by artificially im-

planted joints.

Prevention and treatment of injuries could be improved by better knowledge of the kinematics and dynamics of the normal and pathological knee, by better defining of the contributions of the passive constraints (the cartilage surfaces and menisci and ligaments) and by better understanding the roles of the active constraints (the 15 muscles that act across the knee joint, 12 of which are biarticular with either the hip or the ankle).

This project is developing a comprehensive, mathematically expressed, computer-manipulable model of the human knee joint with which to calculate the kinematics and dynamics of the normal knee. Then, following adequate verification, we will employ the model to simulate the consequence of specific losses observed in the pathological knee—thereby leading to a better understanding of preventive and treatment modalities. The understanding of the normal and pathological knee derived from the model is also expected to contribute to the specifications for improved total knee replacement prosthesis.

Progress—The emphasis during this project year has been on defining the three-dimensional movement volume that is constrained by passive structures in the knee—the articular cartilage surfaces, the menisci, and the ligaments. This passive movement volume is subsequently further influenced by the action of muscles, the forces of which cross the knee articulation.

The new ultrasonic machine for scanning the complex geometry of the knee articular architecture neared completion. The software previously developed for hip geometry measurement was transferred to a new personal computer. A study of the feasibility of determining the structural properties of the menisci using optical measurement techniques was undertaken. Most of the physical property data in the literature concern ligaments that apply loads that cause failure. These are inappropriate for our study: during normal knee activity, the stress and strain experienced by the ligaments is far less. Accordingly, techniques are being developed to measure stress and strain in ligaments at physiologically

relevant levels. New techniques include methods for measuring ligament cross-section in order to establish the stress state and for determining the physiological “resting” length in order to quantify strain.

The experimental data to be used to validate the mathematical model of the knee passive structures are our unique *in vivo* bone movement data. The LED arrays used to acquire this TRACK kinematic information were mounted on bone pins inserted in the femur and tibia of a human volunteer. Since that experiment is not easily reproduced, current studies are comparing data from external arrays (mounted noninvasively) with the bone pin data. A significant advance in the quality of time derivatives of TRACK position and orientation data was achieved through a comparative study of filtering versus smoothing of the kinematic data.

During dissection of human cadaver limbs used on other laboratory projects, the TRACK system is being used to quantify and record the geometry of the origins and insertions of the ligaments and muscles. Generalized musculoskeletal models of the lower limb developed earlier in this laboratory, are being refined and specialized to the specific subject via this anatomical mensuration technique.

Publications Resulting from This Research

- A Comparison of Smoothing and Digital Filtering/Differentiation of Kinematic Data. Murphy MC, Mann RW, *9th Annual IEEE EMBS Conference*, Boston, MA, November 1987.
- Comparison of Finite Helical Axis Estimation to Instantaneous Helical Axis from Noisy Kinematic Data. Van Der Meulen MC, Murphy, MC, Mann RW, *Proceedings of the 34th Annual Meeting, Orthopaedic Research Society*, Atlanta, GA, February 1988.

Biomechanics of Joint Motion

M. Solomonow, Ph.D., and R. D'Ambrosia, M.D.

Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: National Science Foundation; LSU Department of Orthopaedics

Purpose—A systematic approach was designed to study the biomechanics of joint motion, including the various anatomical structures associated with the knee and elbow: bones, ligaments, antagonistic muscle pair, articular surface, receptors, and their complex sensor-motor control drive.

Progress—Several important developments have been found so far, including the fact that the antagonist muscle is always active at a distinct but low level during isometric and slow isokinetic movements. At maximal voluntary effort, the antagonist EMG is inversely released to its moment arm about the joint,

thereby exerting a constant opposing torque to the motion. Furthermore, when flexion-extension movements are performed vertically (to ground), the antagonist EMG compensates for the impact of the gravity vector on the limb mass, and the effective moment arm length changes from the mass centroid

to the joint.

Preliminary Results—The conclusions so far indicate that the antagonist muscle compensates for various internal and external “disturbances,” aiming to maintain joint and motion stability.

Kinematics of the Ankle and Subtalar Joint

Paul Allard, Ph.D., P.Eng.; Hubert Labelle, M.D.; Morris Duhaime, M.D.; Norman Murphy, M.Sc.
Pediatric Research Center, Hospital Sainte-Justine, Montreal, Quebec H3T 1C5, Canada

Sponsor: *Natural Sciences and Engineering Research Council of Canada*

Purpose—The objective of this research project is to develop an analytical tool (model) and technique from which the pattern of motion, occurring at the ankle and subtalar joint, can be quantitatively described. More specifically the objectives are:

1) To determine from 15 amputated lower limbs, the direction vectors of the axis of rotation at: a) the ankle, for the movement ranging from 40 degrees plantarflexion to 20 degrees dorsiflexion and back; b) the subtalar joint, for the movement ranging from 10 degrees eversion to 20 degrees inversion and back. It is hypothesized that the following equations related to body kinematics can be applied to described foot and ankle movements: a) circular motion (fixed axis of rotation), b) euler transformations (fixed center of rotation, spatial rotation), c) screw matrix (instantaneous center of rotation, spatial rotation and translation).

2) To determine the relationship between a non-

invasive technique (using surface markers) and an invasive technique (using osseous markers) for spatial data acquisition. Once the noninvasive technique has been validated, it could be used *in vivo* to assess foot ailments, sprains and rheumatoid feet. Therefore, physiotherapists, orthopaedic surgeons and orthotists, as well as prosthetists, would have a clinical tool for the assessment and treatment of pathological conditions of the ankle and subtalar joint. A better understanding of the kinematics of the ankle and subtalar joint could be helpful in the design of external and internal prostheses as well as orthoses.

This technique could also be used to assess the pattern of motion with the use of different footwear, such as shoes and construction work boots; and sport footwear, such as running shoes, track shoes, and skates.

Ground Reaction Torque and Subtalar Joint Function

N. Messenger, B.Sc., and P. Bowker, Ph.D.

Department of Orthopaedic Mechanics, University of Salford, Salford M5 4WT, UK

Sponsor: *Science and Engineering Research Council*

Purpose—It has been suggested that direct measurement of the torques occurring at the foot-ground interface may yield useful information regarding the efficiency of the “torque-converting” action of the foot/ankle and subtalar joints and hence may provide useful diagnostic information on the pathologies of these articulations. Although this data, as measured using a standard force platform and commonly known as the “Mz” trace, has been briefly men-

tioned in a number of general studies on the force platform, apparently little attention has been paid to it in relation to foot function and hence there is little normative data available.

Progress—The torque (Mz) about the vertical axis was obtained for a group of 20 normal, symptom-free subjects walking barefoot at their own preferred speed across a standard Kistler force platform. Side

and rear view video recordings of each test were analyzed to obtain basic temporal-distance parameters, and an estimation of the degree of ankle inversion/eversion during the stance phase of gait.

A total of five torque traces were obtained for each leg of each subject. Each trace was then normalized to body weight and mean data traces for each leg calculated using a Fourier analysis technique. Two further subjects were tested on five separate occasions to check the method for repeatability. Additionally, a small group of pathological subjects have been tested.

Preliminary Results—Although the principal features of the normal data could be identified in relation to function, considerable intra- and inter-subject variations, both in magnitude and shape, were apparent.

Intra-subject variation—Despite variability in magnitude, it is apparent that the principal features of the data traces are common; that is, the basic pattern of the data is constant and that each trace may be broken down into three distinct parts corresponding to the three phases of stance. This subjective repeatability was also observed in the data obtained from all normal subjects, and within the data obtained from tests carried out on the two subjects used for the repeatability study. However, much greater variation was observed between subjects.

Inter-subject variation—The major difference between subjects occurs in the second phase of stance,

between foot flat and heel-off, and represents a shift of the curve about the zero torque axis. It was postulated that variations from zero torque in this region of the curve would be the most sensitive indicator of abnormal function, and therefore a small group of subjects with known subtalar deficiency have also been tested. Although these results tended to corroborate the assumption of zero “normal” torque, they were all well within the extremes of the normal group data. However, the subjects with pathology were all active and presented with symptoms associated with activity, suggesting the possible presence of “sub-clinical pathology” within the more sedentary members of the normal group.

In comparison with alternative kinematic techniques, the measurement of torque to assess subtalar joint and foot function is a relatively easy task. The data obtained has shown that significant torques are generated throughout the stance phase of gait, and has been found to be sufficiently sensitive to indicate both intra- and inter-subject differences within the normal sample group.

Future Plans/Implications—The initial results of a further preliminary study on a group of early post-treatment ankle fracture patients have proven encouraging, although problems associated with pain compensation have been noted. However, we feel there is justification for further work along these lines.

Biomechanical Evaluation of the Patellofemoral Joint Under Various Degrees of Fixed Rotational Deformities of the Femur

Sanford Anzel, M.D.; Thay Q. Lee, M.S.; Donald Pang, M.D.
Veterans Administration Medical Center, Long Beach, CA 90822

Sponsor: Special Team for Amputations, Mobility, Prosthetics/Orthotics

Purpose—Patellofemoral joint disorders such as fixed rotational deformity of the femur can result from congenital, static or traumatic abnormalities of the bones and joints and/or muscle. These disorders create abnormal stress distribution on the articular surface of the patellofemoral joint that may result in osteoarthritis. The specific objectives of this study were to quantitatively assess the maximum contact pressure distribution on the articular surface of the patellofemoral joint and the load relaxation behavior

of the patella complex under a fixed rotational deformity at various knee flexion angles.

Progress—A special apparatus was designed to be used in conjunction with an Instron Material Testing Machine for biomechanical evaluation of the patellofemoral disorders. This system allows one to introduce various degrees of fixed deformities and knee flexion angles to measure the maximum contact pressure distribution on the articular surface using

Fuji pressure-sensitive film. Further, the load relaxation response of the patellofemoral complex can also be measured. Since the soft connective tissues in the patellofemoral complex exhibit time and history dependent behavior, a series of preliminary experiments were performed to determine the required time for complete recovery of the soft tissue in the patellofemoral complex subsequent to each nondestructive test. For data acquisition, the maximum contact pressure distribution on the articular surface of the patellofemoral joint and the load relaxation behavior of the patella complex at fixed rotational deformities ranging from -30 degrees to

$+30$ degrees at 15 degree increments were obtained. The whole procedure was then repeated at knee flexion angles at 0, 30, 60 and 90 degrees. The results from this study will aid surgeons in determining the degree and onset timing of patellofemoral joint disorder resulting from various fixed deformities of the femur.

Future Plans/Implications—The next step of this study will be a multidisciplinary animal study to characterize the degenerated articular cartilage resulting from fixed rotational deformities.

B. Human Locomotion and Gait Training

WATRACK—A New System for Studying Movement

Zvi Ladin, Ph.D., and Kurukundi R. Murthy, B.S.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: VA Rehabilitation Research and Development Service

Purpose—A new position-measurement system, installed in the Center's Motion Analysis Laboratory, includes two infrared-light-sensitive cameras controlled by an IBM AT PC.

Progress—Small, lightweight infrared-light-emitting diodes (LEDs) are attached to a moving element, whose movement is recorded by the cameras. The light projections on the cameras' back-planes are then electronically integrated, and the three-dimensional position of each LED determined. This information is then stored and transferred to the Center's VAX computer for further analysis. The advanced analysis of the LED position information uses a software package named TRACK, which was

developed at M.I.T. The package includes a series of subroutines that use the above information to calculate the translational and rotational degrees of freedom of rigid segments, instrumented with the LEDs, and attached, for example, to the lower limbs when the kinematics of gait are being studied.

Results—The system has been successfully installed and tested, and its resolution within the system's viewing volume was found to be about one mm for translation and one degree for rotation. The system will be used extensively as researchers at the Center and elsewhere realize its potential. The first clinical study using WATRACK will be of the head movement of a quadriplegic cerebral palsy patient.

Development of a Posture Sensor and Sensory Biofeedback System for Use in Gait Training of the Locomotion Disabled

Hiroyuki Miyamoto

Institute of Biomedical Engineering, Tokyo Women's Medical College, Tokyo 162 Japan

Sponsor: Japanese Ministry of Education

Purpose—In the locomotion-disabled person, such as paraplegic or hemiplegic patients with balance

deficits, information about pelvic inclination is most useful from the point of view of rehabilitation. In

the present study, pelvic inclination and its time derivative in the sagittal and frontal plane during walking are measured by the use of an inclinometer based on the gyroscope principle. This posture sensor system is used to evaluate the gait and its improvement, if any, through rehabilitation. It is also expected to use the information so that the patient may grasp its posture by biofeedback through auditory tone.

Progress—All the information can be obtained from two kinds of sensors: angular sensors put on the pelvis by belts, and foot-switch sensors on the soles of the patient's shoes. The information is acquired and treated on-line in real-time by a 16-bit micro-computer via A/D converter. Several software programs were developed for measurement and data

processing and then tested on the normal subjects' walks and hemiplegic persons' walks.

Preliminary Results—It was clarified by preliminary experiments that a graphic presentation shows basic characteristics of each patient's gait. Clinical results are under evaluation. A prototype of a biofeedback system was designed, fabricated, and tested first on normal subjects.

Future Plans/Implications—It is expected to quantify the gait of each patient, for use in a rehabilitation program and to evaluate its effects. This posture sensor system will be used in combination with the sensory biofeedback system for rehabilitation in some cases.

Measurements of Postural Sway

Zvi Ladin, Ph.D.; Serge H. Roy, M.S.; Mohammed H. Hanno, M.S.
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: Liberty Mutual Insurance Company

Progress—The above-mentioned study has generated a large inventory of data describing postural equilibrium in healthy individuals and in patients with neurological disorders. We are presently re-evaluating these data to test a new mathematical model for postural sway. Unlike standard methods of interpreting stabilograms, the form in which our data appears and the results based on our model clearly emphasize differences in postural sway and provide a means of understanding the motor-control scheme that directs the movement.

To further understand the model as a control

process, the statistical properties of the stabilogram are being studied. An algorithm to calculate the angular rotations of the center-of-pressure "foot-print" has been developed. The algorithm is used to study the statistical properties of the distribution of rotations so that the "random" aspects of the stabilogram can be studied. A stochastic model of the process will then be developed, and the behavior of the model in response to different processes and under different boundary conditions will be studied. Such a model may explain some basic issues in the postural control of the neuromuscular system.

A Model for Postural Sway

Serge H. Roy, M.S.; Zvi Ladin, Ph.D.; Mohammed H. Hanno, M.S.; Carlo J. De Luca, Ph.D.
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: Liberty Mutual Insurance Company

Purpose—When an individual stands erect, the body makes minor movements over the location of the feet, for the human body is incapable of remaining perfectly still. Standing erect is a complicated task

which most individuals accomplish with varying degrees of ease. The purpose of this study is to increase our understanding of the mechanisms that control posture in order to measure and quantify

the amount of dysfunction in individuals with movement disorders.

Progress—Toward that goal, we have begun to measure and analyze the stabilograms of individuals. Stabilograms are the plots that describe the continual displacement of the center of pressure (sway) in the horizontal plane of the feet as an individual stands still. Stabilographic measures have been used for many years, but their usefulness has not lived up to expectations, mainly because the tracings obtained thus far do not have easily describable parametric behavior.

Our approach to modeling the behavior of the stabilogram is to consider the sway as a random variable that may be described by Brownian motion. When the stabilogram is plotted as a variable of the diffusion equation that describes Brownian motion,

the resulting curve suggests that the modeling approach is correct. We plan to continue studying the applicability of the model with the intention of extracting information concerning the control properties that govern postural sway.

The model is being tested by investigating whether a subject exhibits a preference to sway in a particular direction during erect stance. This can be measured by considering the stabilogram as a series of line segments joining the consecutive center of pressure coordinates. A computer program was developed to measure the magnitude and direction of the angles subtended by each contiguous pair of line segments. Histogram plots of these "sway angles" are being computed and analyzed for all of our previously collected stabilogram data. A manuscript is under preparation to describe these observations.

The Clinical Application of Gait Analysis

C.B. Meadows; I.R. Loudon; T.D. Dick

Bioengineering Centre, Princess Margaret Rose Orthopaedic Hospital, Edinburgh EH10 7ED, Scotland

Sponsor: *Lothian Health Board; Spastics Society; University of Edinburgh; Women's Royal Voluntary Service; Ferranti P.L.C.*

Purpose—Our objective was to establish a biomechanical gait analysis facility for the purposes of clinical service, clinical research and teaching.

Progress—A gait analysis facility has been established utilizing a Vicon TV-computer motion analysis system (Oxford Metrics), a force measurement platform (Kistler Instruments) and a biological telemetry system (M.I.E. Medical Research Limited).

This facility will be used for a wide range of investigations relevant to the activities of an orthopaedic hospital. A principal activity, initially, is an investigation of the use of biomechanical gait analysis for the assessment of cerebral palsied patients in a routine orthopaedic clinic. This work is being carried out in collaboration with Tayside Rehabilitation Engineering Services, Dundee, Scotland.

The Effects of Proximal Tibial Osteotomy and Tibial Tubercle Elevation on Knee and Ankle Joint Loading

M. Milner, Ph.D., P.Eng., C.C.E.; P. Tepperman, B.Sc. M.D., F.R.C.P.(C); A. Gross, M.D., F.R.C.S.(C); I. Harrington, F.R.C.S.(C)

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: *The National Health Research and Development Programme, Health and Welfare, Canada; the Physician's Services Incorporated Foundation of Ontario, Canada*

Purpose—The aim of this study is to objectively measure changes in gait parameters resulting from valgus high tibial osteotomy for osteoarthritis of the medial compartment of the knee. The effects of the osteotomy and valgus realignment of the ankle and

foot will be analyzed and the use of prophylactic foot orthoses in correcting heel and mid-foot alignments will be explored.

The specific goals of this project include: 1) using the results of gait assessment, we hope to predict

the optimal size of tibial wedge and hence the angle of knee alignment that will best reduce pain and improve functional gait; and 2) investigating the minimization of secondary stresses at the ankle through the use of simple shoe wedges and orthoses.

Progress—Patients undergo gait assessments prior to surgery and at 3, 6, and 12 months postoperatively. Each gait assessment consists of 3 runs of standing on one leg and 5 runs of walking data for each side. Simultaneous recordings of electromyography, force plate, footswitch and kinematic data are taken for each run. Electromyography is recorded from the vastus medialis, rectus femoris, tibialis anterior, gastrocnemius, medial and lateral hamstrings bilaterally. Areas of contact under the feet are recorded from a glass-top platform which has light sources on either side.

Functional and clinical assessments include passive and active knee range of motion, knee strength, and a questionnaire dealing with pain and activities of daily living. Comprehensive models of the knee and ankle have been developed which incorporate the internal forces due to muscle and ligament structures as well as the external moments of force about the joint. From this model, individual muscle forces, ligament forces, the overall joint load and the location of the joint load in the knee compartments, can be calculated.

Preliminary Results—Thirty patients have been assessed preoperatively, and of these, eleven patients have completed the protocol. Four patients have completed their 6-month assessment, two patients have completed their 3-month assessment, and seven patients have withdrawn from the study. All normal

subjects have completed gait assessments. A total of 59 gait studies were completed in 1986.

Preliminary results of eight subjects were presented at the North American Congress on Biomechanics (NACOB) in August in Montreal, Quebec. Results include a decrease in mean maximum knee joint load per kg body weight from 2.485 ± 0.774 N/kg preoperatively to 1.740 ± 0.297 N/kg postoperatively. This maximum occurred at an average of 17.4 ± 7.4 percent of the gait cycle preoperatively, and at an average of 29.3 ± 12.7 percent of the gait cycle postoperatively. These results may be compared with average normal values of 2.500 ± 0.500 N/kg maximum knee joint load per kg body weight occurring at 21.5 ± 8.2 percent of the gait cycle. An average preoperative value of 8.00 ± 3.30 degrees of varus compared with an average postoperative value of 9.25 ± 4.55 degrees of valgus at the knee leads to a shift of percent joint load on the medial side of the knee from an average of 85.69 ± 8.42 percent preoperatively to an average postoperative value of 68.94 ± 16.68 percent. Mean values for normal subjects were determined to be 3.2 ± 2.7 degrees of varus at the knee, and 92.0 ± 10.0 percent joint load on the medial side of the knee.

Other results include an increase in the mean speed of walking, from 0.800 ± 0.208 m/s preoperatively to a mean post-operative speed of 0.896 ± 0.174 m/s, and a significant decrease in subjective perception of pain from the preoperative to the postoperative period.

Publications Resulting from This Research

Effects of Proximal Tibial Osteotomy on Knee Joint Loading. Cairns B, Naumann S, Tepperman P, Kekosz V, *Proceedings of the North American Conference on Biomechanics* 11:283-284, Montreal, Quebec, Canada, 1986.

Quantitative Measures for Assessing Therapeutic Effectiveness

Max Donath, Ph.D.; Joan Dzenowagis, R.N.; Ted Morris, B.S.; Jennifer Pavlovic, B.S.

Human Motion Laboratory, Rehabilitation Engineering Center, University of Minnesota, Minneapolis, MN 55455

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—These studies will develop and test measures capable of evaluating the effects of intervention strategies in the management of arthritis; develop a reference database for the parameters of gait, range-of-motion, and anthropometric data for use in pattern recognition studies; and begin preliminary as-

essment of subjects displaying pathology or symptoms associated with gait.

Progress—Our approach has been directed towards the development of a gait vector which exhibits both direction and magnitude and defines a point in a

multi-dimensional space. Each point represents the measured parameters at a particular time along the gait cycle; thus, a series of vector-defined points will form a time-dependent curve. Given a sampling of normal curves from subjects who are close in age and size to the subjects being tested, a mean normal curve can be determined. A bounding envelope around the mean normal curve is defined to contain normal gait function based on a reasonable statistical level of confidence. This boundary defines a discriminant function for the recognition of pathological patterns and a baseline for comparing the effects of different treatment modalities. Gait vectors for individual subjects are calculated from the patient database, which includes data from patients with osteo, rheumatoid, and other types of arthritis.

If a subject's gait deviates outside the normal boundary region at any point in time, then the distance between the point and the boundary is computed as a function of time. The vector direction indicates which parameters are contributing to the abnormal gait function. The vector magnitude indicates the degree of abnormality of these parameters. As the subject's gait curve is compared to the normal boundary, each deviation is added to a

running sum to give a measure indicative of total deviation from normal. The time history of the actual deviation from the mean curve is also considered. The summation gives a quantitative measure from normal, while the time history of deviation indicates the source of the deviation and identifies the portion of the cycle where significant deviations have occurred.

Preliminary Results—Interpreting large amounts of data in traditional formats has not been very successful. In order to overcome this difficulty, we have developed techniques for animating a human figure on a computer screen in which the limbs are driven by the data collected in the lab on our population of subjects.

In addition, three-dimensional graphs showing scatter-plots of the data have been developed. These graphs enable the clinician to analyze and interpret patterns in data that may not be discernible from two-dimensional graphs. The walking figure and the associated data can be viewed from any direction. Zooming facilitates close-up views of specific gait anomalies.

A Telemetric Data Acquisition and Processing System for Biofeedback Training and as a Diagnostic for Human Movement Training

Woodie Flowers, Ph.D.

Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—This work stems from an initial effort to improve gait training for above-knee amputees, and is now branching into application for others with similar gait pathologies. Earlier work resulted in development of a self-contained biofeedback system that is worn by the amputee during gait training sessions. Hip angle is measured by a radio goniometer and axial load is determined by strain gauges in the shank of the prosthesis. In this system, called the MIT Strider, these parameters are recorded in a waist pack, which also provides feedback to the patient as a tone that varies with the measured load or angle. The Strider has been used successfully in a clinical setting.

Modifications to this system, including a wireless data-link that telemeters the data from the patient

to a remote personal computer, yielded the MIT Trainer. With the computer, data can not only be stored and replayed later, but generalized graphics software has been written allowing visual biofeedback in the form of stick figure images on the CRT, which move as a representation of the measured angle and load. The auditory feedback can be a tone that sounds when a preset threshold angle is attained.

Progress—The Trainer system has been applied in gait training sessions with amputees, as well as in measurement of hip angle during squat weightlifting exercises, and in feedback of knee angle during leg extension exercises for an athlete undergoing knee rehabilitation. It has also been recognized that many hemispherically affected stroke patients exhibit gait

pathologies similar to those of A/K amputees, including loss of control at the ankle and knee and lessened extension at the hip during stance. Thus, the hip angle measurement facet of the system has been used in gait therapy sessions with two stroke patients.

The first of these patients was extremely attentive to the system feedback, consciously working to attain the threshold angle, and therapists were very happy with the system's application. The second patient illustrated one hardware shortcoming, as she had such minimal control at the hip that the leg sometimes rotated externally during swing. This gross out-of-plane motion of the radio goniometer caused some unreliable output, indicating that the method of joint angle measurement utilized in the system may merit further investigation. Overall, patient and therapist response was quite positive, and the system is undergoing continued testing with stroke patients. Plans are also underway to utilize

the device with other patients suffering motor coordination deficits, such as those with cerebral palsy or head and spinal cord injuries.

Publications Resulting from This Research

- Human Movement Biofeedback Training and Diagnostic System.** Belot JR, Flowers WC, *ACEMB*, Baltimore, MD, September 13-16, 1986.
- A Radio Goniometer for Use in Training Above/Knee Amputees.** Cullen CP, Flowers WC, *Proceedings of the 2nd International Conference on Rehabilitation Engineering*, 268-269, Ottawa, Canada, 1984.
- A Preliminary Report on the Use of a Practical Biofeedback Device for Gait Training of Above/Knee Amputees.** Flowers WC, Cullen CP, Tyra KP, *Journal of Rehabilitation Research and Development*, 23(4):7-18, October, 1986.
- Computer Control of A/K Prostheses Using Sound Leg Landmarks.** Linske KA, Flowers WC, *ACEMB*, Chicago, IL, September 30-October 2, 1985.
- A System for Measuring the 3-Dimensional Gait of an Above/Knee Amputee Wearing a Prosthesis Simulator.** Stein JL, Flowers WC, *Proceedings of the 2nd International Conference on Rehabilitation Engineering*, 233-234, Ottawa, Canada, 1984.

Feasibility Study: Evaluation of Total Knee Replacement by Gait Analysis

Sheldon R. Simon

The Brigham and Women's Hospital, Inc., Boston, MA 02115

Sponsor: *National Institutes of Health*

Purpose—This grant is requested to develop three areas of special interest. The first is applied research in which we aim to: 1) develop a necessary and sufficient database for the rational planning of health services to arthritics, and 2) develop and evaluate model components of cost-effective health care delivery for arthritis patients. Thus, under Community Component, we propose to develop and critically evaluate: a 7-day rehabilitation work schedule; a model health care system for arthritis disability; stepped-up rehabilitation services to homebound patients; a system of follow-up of rheumatic disease patients discharged from a tertiary care facility; a patient-oriented strategy to improve clinical outcomes; and an educational strategy for the primary prevention of low back injuries in the work place. As one of the 4 major joint replacement centers in the world, we propose to evaluate the

cost-effectiveness of joint replacement by a multi-dimensional outcome assessment. We seek to document the economic burden to arthritics and shortfalls in the present health care reimbursement scheme. We propose to evaluate the means by which interventions can be evaluated, and compare the relative merits of existing health status functional instruments.

The second priority is the development of a Core Unit for quantitative research methods, Clinical Epidemiology and Evaluation Research, which would overlap with many activities of the Center and would aid investigators in training and establishing investigators. The Unit would support at least 10 projects, from the day-to-day management of special disease registries, to clinical studies directed at improving clinical strategies and decision making in rheumatology, and applications of basic research.

A Clinical Gait Recording System

W.V. James, F.R.C.S.; J.F. Orr, Ph.D.; D. Weir, Ph.D.

W.M. Automation Ltd., Carrickfergus, Northern Ireland and Rehabilitation Engineering Centre, Musgrave Park Hospital, Belfast, Northern Ireland

Sponsor: The Northern Ireland Prosthetic Orthotic and Aids Service

Purpose—This continuing project is concerned with the production of a portable microcomputer-based gait recording system which is suitable for clinical use.

Progress—The Foot Pressure Profile Platform (FPPP) continues in production as the "Musgrave Footprint." The instrument records and presents pressure distribution under the sole of the foot, either

during standing or walking.

Results—Information relating to center of pressure, maximum pressure and pressure/time characteristics may be examined on screen or on print-outs. Either one or two pressure plates may be used, interfaced to either a BBC or an IBM microcomputer. Software options continue to be augmented as is the resolution of the pressure platform.

Gait Abnormalities in Hemiplegia: Their Correction by Ankle-Foot Orthoses

Justus F. Lehmann, M.D.; Sandra M. Condon, M.S.; RPT; Robert Price, MME; Barbara J. de Lateur, M.D.

Department of Rehabilitation Medicine, University of Washington, Seattle, WA 98195

Sponsor: None Listed

Purpose—Hemiparetic gait is characterized by slow speed and poorly coordinated movements. Because the values of gait parameters vary with changes in speed, the slow speed that is typical of hemiparetic gait necessitates applying controls for the influence of speed when comparing hemiparetic and able-bodied persons.

Progress—Gait kinetics and kinematics were measured in seven hemiparetic and seven able-bodied adults to compare their gait patterns at similar speeds and to assess the effectiveness of ankle-foot orthoses which were double-stopped in 5 degrees of dorsiflexion or 5 degrees of plantarflexion.

Results—Hemiparetic persons ambulating without the orthoses had a shorter step length, longer duration stance, and shorter duration swing than normal. They displayed greater than normal flexion of the affected hip during midstance, which, by putting

the center of mass farther in front of the knee, may explain the increased knee extension moment due to vertical force. Affected hip adduction during single support was less in hemiparetic persons than in able-bodied persons, indicating a decreased lateral shift to the paretic side. During the swing phase, the affected limbs of hemiparetic persons were in less knee flexion and less dorsiflexion than normal, necessitating circumduction to achieve toe clearance. Ankle-foot orthoses increased walking speed to normalize heelstrike duration through use of an optimally adjusted plantarflexion stop. An improperly adjusted orthosis may produce an exaggerated knee flexion moment resulting in knee instability.

Publication Resulting from This Research

Gait Abnormalities in Hemiplegia: Their Correction by Ankle-Foot Orthoses. Lehmann FJ, Condon SM, Price R, de Lateur BJ, *Archives of Physical Medicine and Rehabilitation*, 68, 1987.

C. Other

Optimal Biomechanical Design/Development of Arm-Powered Mobility Devices

Michael Zomlefer, Ph.D.; Douglas Schwandt, M.S.; Jeffrey Aldrich, Ind.Des.; Tim Hight, Ph.D.; Doug Martin, Ph.D. Candidate; Russ Miller, B.S. Candidate; Jason Lee, M.S.; Linda Hollis, B.S.
Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The development of upper limb simulation and modeling tools is important to future design efforts attempting to optimize arm-powered drive systems and create better mobility and exercise devices for individuals with lower limb disability. Modern control theory, when coupled with human biomechanical performance measurements, can lead to nearly optimal arm-powered drive systems. This involves the development of a tractable, computerized, biomechanical model for the upper limb as it applies to a broad spectrum of arm-propulsion tasks. Given specified performance criteria (such as maximum power output or maximum efficiency), this model may then be used to quickly create optimal configuration and dimensions for any proposed drive system and purpose.

Progress—Experimental results obtained from subjects operating a variety of arm-powered ergometer drive systems will be used to help define and refine the biomechanical model of the upper limb performing optimizable ergonomic tasks, applying modern optimal control theory. In order to develop a more universal mathematical model, several drive and load systems will be employed, each with such variable features as crank length for arm cranking experiments, or lever length and pivot position for oscillating lever propulsion. Kinematic and dynamic data will be acquired, and analyzed with simultaneously collected electromyograms (EMGs).

The rotary crank and reciprocating lever laboratory arm-powered ergometer systems have been designed and fabricated. Design work was carried

out using the computer-aided design facilities at the Stanford Center for Design Research. Mathematical equations of motion describing the dynamics of the arm-cranking task have been developed for entry into the computer. Dynamic and EMG data acquisition systems are being assembled in preparation for the initial round of experimentation and analysis. Experiments will be carried out in conjunction with Santa Clara University Biomechanics Laboratory.

Results—Initial experimental test runs are underway on the ergometer. This will be followed by variable arm-crank length and shoulder to crank center experiments on able-bodied and paraplegic subjects. Data will be analyzed and results reported.

Future Plans/Implications—It is anticipated that a 3-dimensional extension of the computer model will be the subject of work building upon this study. In addition, the combined theoretical/experimental approach of this study can easily be extended to other functional tasks such as reaching, grasping, moving, and manipulating objects. Better models for limb dynamics will also serve functional electrical exercise and biofeedback strategy research, through improved understanding of muscle activation sequence.

Publications Resulting from This Research

A Modular Multiple Drive/Load Ergometer for the Development of an Optimal Biomechanical Model of the Upper Limb. Schwandt DF, Aldrich JC, Zomlefer MR, *RESNA 9th Annual Conference*, 6:429-431, Minneapolis, MN, June 1986.

Biofeedback System for Postoperative Hand Rehabilitation

Donald Neth, M.S.; Kevin Waters; Steven I. Reger, Ph.D.

Department of Musculoskeletal Research, The Cleveland Clinic, Cleveland, OH 44106

Sponsor: *The Cleveland Clinic Research Foundation*

Purpose—A biofeedback device has been developed for use in postoperative rehabilitation of the hand. A varied program of exercises can be prescribed and monitored by adjusting the different settings on the device. The patient is asked to squeeze a rubber bulb that is attached to the biofeedback unit. The force of the squeeze, as well as the duration and frequency of squeezing, are monitored. If the patient fails to squeeze the bulb the prescribed number of times and with the prescribed force, a warning light will be activated. If the patient still fails to squeeze the bulb in the prescribed manner, a buzzer will sound. As a reward for correct completion of a

prescribed task, a television or record player will remain operating for the user's viewing enjoyment. When used with children (or some adults), this reward can serve as an effective reminder; incomplete and incorrect performance of the hand exercise task will result in the deactivation of the television set.

Progress—A simplified prototype of the device has been built and successfully tested in the Cleveland Clinic Department of Occupational Therapy. A second prototype with full capabilities is currently being assembled.

Dynamic Positional and Electromyographic Monitoring of Sitting Posture

M. Milner, Ph.D., P.Eng., C.C.E., and W. Lotto, M.D., F.R.C.S.(C), F.A.C.S.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: *Hospital for Sick Children Foundation; The National Health Research and Development Programme, Health and Welfare, Canada*

Purpose—This study was designed to objectively quantify the activity of selected muscles while in the sitting position. Both normal children and children with cerebral palsy (CP) are being studied while changes of seat inclinations are made. The specific goals of the project include: 1) detection of muscle imbalance (asymmetry) during sitting; 2) investigation of the effects of techniques aimed at improving spinal alignment; and 3) data collection concerning sitting posture of children with CP which will assist in the design of new sitting systems.

Progress—This study involves 20 children: 10 normal and 10 with cerebral palsy (mildly involved spastic diplegia) ranging in ages from 5 to 12 years old. The protocol consists of four sessions, each divided into two ten-minute phases. A 20-minute period begins to approach the functional sitting time for these children during typical classroom activity.

The protocol will enable us to compare the postural parameters between normal (or 0 degree) sitting, and sitting on either a 10 degree or 15 degree

forward tilting seat base; and between relaxed sitting at a forward 15 degree tilt and maximum voluntary extension of the back. Monitoring 0 degree sitting angle in the second phase facilitates the observation of any possible fatigue factors.

Preliminary Results—To date, 15 children, 8 with cerebral palsy and 7 normals, have completed the protocol. It appears that the optimal angle for the seat base inclinations is closer to 10 degrees than 15 degrees, because although the postural parameters of trunk stability and spinal elongation are similar at both 10 degrees and 15 degrees, muscle activity is greater at 15 degrees than 10 degrees.

The improvements in sitting posture observed in children with cerebral palsy, obtained by tilting the seat base forward, are of greater therapeutic value despite the increased back extensor muscle activity. Tipping the seat base forward causes an increase in mid-thoracic and lumbar EMG, although bilaterally, the muscle activity became more symmetrical. Generally, hamstring activity was reduced.

The changes in muscle activity were much more pronounced in children with cerebral palsy than with normal children. An anteriorly tipped-seat appears to facilitate spinal elongation and increase trunk stability (reduce radius of movement) in the cerebral palsy child.

Future Plans/Implications—The present monitoring system and protocol appears to be an objective method of evaluating posture in children with cer-

bral palsy. That is, trunk stability, spinal elongation, and back extensor muscle electromyographs can be monitored accurately and objectively. The work in this area will continue.

Publications Resulting from This Research

Positional and Electromyographic Investigation of Sitting Posture in Children with Cerebral Palsy, Bablich K, Sochaniwsky A, Koheil R, *Developmental Medicine and Child Neurology* 28(S53):25, 1986.

Mechanics of Rising From the Seated Position

T.J.C. Harte, H.Dip. Pros./Orth.; **W.V. James, F.R.C.S.;** **R. McIlhagger, Ph.D.**

Department of Mechanical and Industrial Engineering, The University of Ulster, Jordanstown, Northern Ireland and Rehabilitation Engineering Centre, Musgrave Park Hospital, Belfast, Northern Ireland

Sponsor: *The Northern Ireland Prosthetic Orthotic and Aids Service*

Purpose—The aim is to develop and evaluate a system whereby a disability can be defined and its progress, either degenerative or corrective, can be monitored by analyzing the subject's mode of rising from a seat.

Progress—A low cost force plate has been designed and constructed to measure the reaction force, during standing, under the feet. A similar instrument

is being constructed for the seat of a variable geometry chair, for which armrests are also being developed with instrumentation to measure forces. Electrogoniometers are being used to record joint angles of the leg and their interfacing with a micro-computer is well advanced. It is anticipated that preliminary results will be recorded during the latter months of 1987.

A New Approach in Muscle Training to Rehabilitate the Hand in Leprosy

R.C. Sharangpani, M.S. Dip. Sports Medicine; **V.N. Kulkarni, B.Sc.(PT)PGDR;** **J.M. Mehta, M.B.B.S.**
Dr. Bendorawalla Leprosy Hospital, Kondhawa, Pune 411022, India

Sponsor: *Poona District Leprosy Committee*

Purpose—In leprosy a hand, with its atrophic musculature, poses a formidable challenge as far as anesthesia during tendon transfer surgery and rehabilitation after surgery is concerned. An ideal rehabilitative exercise in such circumstances should be inexpensive, easy to perform repeatedly, and should produce a normal hand function as soon as possible. A sheet of newspaper, when crumpled by hand into a ball, constitutes an ideal exercise for rehabilitation of the hand following surgery. The exercise increases the speed of finger movement, as well as static and dynamic strength and coordination between fingers in space (due to infinite positional combinations). There is rapid increase in the flexibility of fingers with high integration of extrinsic as well as intrinsic muscles of the hand.

With this exercise we have been able to improve the function of the hand remarkably well and the rehabilitation time following surgery is drastically reduced, with function returning close to normal. The patient holds one corner of the paper between his thumb and index finger and starts gathering it into his hand without the aid of his other hand or any other structure in the vicinity. He is advised to make use of all fingers consciously. Once he is able to gather the paper in his hand; he compresses it into a small firm ball which can be compressed no more.

Progress—Fifty patients ranging from 20 to 55 years of age and who had undergone tendon transfer surgery for opponens and lumbrical replacement

using sublimis as a motor participated in the study. The following schedule was observed in these cases: a) three weeks in plaster cast following surgery; b) achievement of voluntary lumbrical position without splints within 1 week; c) start with paper crumpling by the end of first or beginning of second week; d) complete fist by the end of third week; and, e) total rehabilitation time five to eight weeks following surgery.

Results—It was noticed that the achievement of a fist was very rapid (average time being 2 to 3 weeks, particularly observed in the donor finger). With this exercise both initiation and completion of profundus action at the distal interphalangeal joint of the donor finger was quite early as compared to the previous conventional physical therapy methods. Profundus also worked freely at the proximal interphalangeal joint and took over the sublimis function quite well. There was an enhanced effect on the gliding of profundus in the donor finger. Re-education of profundus to function without sublimis in the donor

finger was achieved very quickly and efficiently.

The average time for the completion of fist through paper crumpling was 12.4 days in 36 patients and 33.5 days in the other 14 patients. The average time for the completion of fist after removal of the plaster cast was 26.8 days in 30 patients and 57 days in the other 20 patients. Patients who required more than two weeks to achieve the fist had one of the following problems post-operatively: delay in achievement of voluntary lumbrical position; stitch abscess; or severe adhesions round the profundus tendon of the donor finger.

Paper crumpling constitutes an ideal exercise for rehabilitation of patients following hand surgery, especially in leprosy. The exercise is easy to understand, inexpensive, and can be done any time, anywhere, and as many times as possible. It gives excellent visual feedback and does not injure the insensitive hands. The exercise adjusts itself to the needs of the patient remarkably well and allows for a gradual rate of increase in the performance of the task.

Comparison of Floor Sitting and Wedge Kneeler: Their Effect on Posture and Upper Extremity Range of Motion in Children with Cerebral Palsy

Lynne Logan, M.A., P.T., and Maureen Jakubson, OTR
Special Children's Center, Inc., Ithaca, NY 14850

Sponsor: Special Children's Center, Inc., Ithaca, NY

Purpose—The objectives of this project were to apply the flexible ruler technique for measuring lumbar curve changes to a pediatric population; to develop measures of active, functional upper extremity range of motion; and to document the changes in posture and functional range for children with cerebral palsy in various sitting positions/equipment using these measures. Children with cerebral palsy frequently exhibit an uncorrected sitting posture composed of posterior pelvic tilt, flattened lumbar curve, and thoracic flexion. These are associated with shoulder internal rotation and upper extremity postures which are considered to limit upper extremity range of motion. Several types of adaptive seats have been proposed to correct posture. Corrected hip and trunk posture is hypothesized to correct upper extremity posture and therefore to affect active, functional range of motion. However, clinically useful and accurate measures

of posture and active, functional range of motion have not been implemented or tested with a pediatric population.

Progress—A pilot study has been completed using a 4-and-a-half-year-old child with spastic quadriplegic cerebral palsy. Lumbar curve measurements have been recorded using the flexible curve when seated initially and after upper extremity range measurements have been taken. The conditions measured were: floor-sitting independently, bench-sitting on a level bench, and bench-sitting on a wedge bench with a 45-degree forward tilt. The wedge bench was developed at the Special Children's Center to replace floor sitting for children with spastic type cerebral palsy. The design is similar to a back chair which combines both sitting and kneeling. Upper extremity range is recorded on graph paper attached to an upright easel. The graph

is level. The horizontal axis is placed at shoulder level. The vertical axis is placed at midline. The point touched with the right and the left index finger is marked on the graph paper at 0, 30, 90, 120, 150, and 180 degrees. The distance from the child's anterior, superior, and iliac spine to the easel is the same in each condition. The child's seat is wooden and a seat belt is used to prevent the child from leaving the seated position.

Preliminary Results—The flexible curve has allowed static lumbar positions to be recorded. Measurements of the lumbar curve have changed in the expected direction. The curves are apparently posterior in floor-sitting, flattened in level bench-sitting, and anterior in wedge bench-sitting. The upper extremity range measurements also show the ex-

pected change on gross inspection of the graphs. Range increases from floor-sitting to level bench-sitting to wedge bench-sitting. Statistical analysis remains to be completed. However, it has been difficult to relate the lumbar curve measurements to the range measurements because of the dynamic spinal movement during active range of motion in the upper extremity. Each measure taken separately does appear to support the use of special seating to correct posture and to improve functional range.

Future Plans/Implications—We plan to continue this study by adding subjects and attempting to develop a dynamic measurement of lumbar curve in pediatric patients. Suggestions from the field on this topic would be most welcome.

Design of Instrumentation to Quantify Upper Extremity Motor Control of Children with Cerebral Palsy: Pilot Study

B. McClenaghan, P.E.D.; K. Bablich, M.Sc., R.P.T.; A. Sochaniwsky, B.Sc.; R. Koheil, Dip.P. & O.T., B.Sc.(P.T.)
Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: *United Cerebral Palsy Research Educational Foundation*

Purpose—The aim of this project was to develop instrumentation to quantify motor performance of the upper extremity and monitor muscular responses contributing to trunk stability during a reaching task. Emphasis was placed upon developing a standardized experimental task and instrumentation to collect temporal and muscular measures using an automatic data acquisition system.

Progress—Speed and time measures have been used extensively in motor control research to quantify performance. A choice response time task for three positions was designed to quantify upper extremity motor function. Instrumentation consisted of a series of pressure sensitive switches (6.5 cm x 6.5 cm) mounted in a row on an adjustable table. This table is placed directly in front of the subject, matching the center switch with the midline of the body. Distance between the switches is easily adjustable to accommodate individual abilities of each subject. EMG activity was monitored from three muscle sites: anterior deltoid, and bilaterally from the lumbar erector spinae (L3 segmental level).

Software developed to run the experimental protocol contained subroutines to: 1) input demographic

data; 2) sample, average and compute the EMG threshold level; 3) randomly present a stimulus or cue; 4) strobe the computer to sample EMG data; and, 5) store and calculate temporal response data.

Results—Four children with cerebral palsy (spastic diplegia) aged five to eight years old participated in the study. It was observed that non-dominant lower back erectors showed activation prior to the deltoid muscle and the dominant side of low back extensor. This observation provided valuable insight into the coordination of the muscular actions contributing to trunk stability during the performance of a reaching task.

Future Plans/Implications—Further development shall be directed towards refining software and data acquisition with the use of one computer only, and evaluating the effects of selected seat inclinations on upper extremity motor control.

Publications Resulting from This Research

Design of Instrumentation to Quantify Upper Extremity Motor Control of Children with Cerebral Palsy. McClenaghan BA, Bablich K, Sochaniwsky A, Koheil R, *Proceedings of the Ninth Annual Conference on Rehabilitation Technology*, Minneapolis, MN, 6:158-160, June 1986.

X. Wound and Fracture Healing

Stress Analysis of Internal Fracture Fixation of Long Bones

Gary S. Beaupré, Ph.D.; Dennis Carter, Ph.D.; Tracy Orr, M.E.; John Csongradi, M.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objectives of this study are to develop accurate, nonlinear, three-dimensional finite element models of long bones treated with compression plate fixation.

Progress—Using mathematical models, we are investigating the influence of plate fixation on the internal stresses in long bones subjected to all known *in vivo* loading modes. The variables we are studying include: plate geometry, plate/bone fixity, and screw tightness. The mathematical models are based upon the finite element technique. The models will be subjected to all physiological loading modes, i.e., axial, bending and torsion loads. Plate geometry is studied by designating either stainless steel or titanium in the finite element model. Coulomb friction is used to vary the amount of plate to bone and screw to plate fixity. Screw tightness will be varied from zero to the maximum value found in the literature from clinical studies. Idealized *in vitro* bone models have been made from magnesium and phenolic tubing. These will have fixation plates and strain gauges attached and be subjected to the same loads as for the mathematical models.

Results—Finite element models of idealized plated long bones have been created. The effects of screw tightness and plate material have been studied. The models have been analyzed using three different quarter-symmetric loading conditions and two half-symmetric loading conditions. Numerous publications resulting from the research have been presented, published, or are in the process of being published.

Future Plans—Two different mechanisms used to alter the transfer of load from bone to plate will be

studied next. Mathematical models have already been developed. Results from these models will be compared with physical models using plates attached to osteotomized phenolic tubes using full-length screws and using shortened outer screws.

Publications Resulting from This Research

- The importance of friction interfaces in mathematical models of plated long-bones. Beaupré, G.S., Carter, D.R., Orr, T.E. and Csongradi, J., *Trans Orthop Res Soc* 11:476, 1986.
- The incorporation of friction interfaces in a non-linear, finite element model of a plated long bone. Beaupré, G.S., Carter, D.R., Orr, T.E. and Csongradi, J., *Proc 5th European Soc Biomech* 5:59, 1986.
- The importance of frictional interfaces in mathematical models of plated long-bones. Beaupré, G.S., Carter, D.R., Orr, T.E. and Csongradi, J., *Orthopaedic Transactions* (in press).
- Mechanisms to alter load transfer along the diaphysis in plated bones. Beaupré, G.S. and Carter, D.R., *Trans Orthop Res Soc* 12:386, 1987.
- The incorporation of friction interfaces in a non-linear, finite element model of a plated long bone. Beaupré, G.S., Carter, D.R., Orr, T.E. and Csongradi, J., accepted for publication, *Biomechanics: Current Interdisciplinary Research*, Nijhoff Publishers, 1987.
- Diaphyseal load transfer in plated bones. Beaupré, G.S. and Carter, D.R., *Orthopaedic Transactions* (in press).
- Methods to reduce stress shielding in plated bones. Beaupré, G.S. and Carter, D.R., *Proceedings of the Tenth Annual Conference on Rehabilitation Technology RESNA*, San Jose, CA, pp. 826-828, 1987.
- Short Communication: Warping of cross sections in the torsion of long-bones with internal fracture fixation plates. Beaupré, G.S. and Carter, D.R., *J Orthop Res* 5:296-299, 1987.
- Stresses in plated long-bones: The role of screw tightness and interface slipping. Beaupré, G.S., Carter, D.R., Orr, T.E. and Csongradi, J., *J Orthop Res*. (in press).
- The incorporation of friction interfaces in a non-linear, finite element model of a plated long bone. Beaupré, G.S., Carter, D.R., Orr, T.E. and Csongradi, J., presented at the International Conference on Trends in Human Biomechanics Research and Applications in Medicine and Surgery, Riga, Latvia, Sept. 12-15, 1986.

Testing of Design Parameters for a Prototype Piezoelectric Internal Fixation Plate

G.V.B. Cochran, M.D., M.Sc.D.; M.P. Kadaba, Ph.D.; V. Palmieri

Orthopaedic Engineering and Research Center, Helen Hayes Hospital, W. Haverstraw, NY 10993 and Surgical Research Service, Veterans Administration Medical Center, Castle Point, NY 12511

Sponsor: VA Rehabilitation Research and Development Service; Walter Scott & Lyons Foundation; New York State Department of Health

Purpose—Stimulation of bone healing by microampere electric currents is now a recognized form of clinical treatment. For this purpose, various devices are available that aim to improve the healing of bone in problem cases, particularly for individuals with delayed nonunion. Typically, the stimulatory current is provided by a battery-powered device that delivers current to bone via electrodes or by an external electromagnetic device that induces currents in bone. Our purpose is to develop a novel approach to electrical stimulation of bone healing that employs microampere currents generated during physiological loading by a piezoelectric material that is incorporated as part of an internal fixation plate. Alternatively, current can also be generated by external application of ultrasound to the skin over the plate. Because piezoelectric materials produce an electrical charge under mechanical loading, the "piezoplate" will represent an implant that will not only stabilize bone but also will provide an internal source of electrical stimulation in response to physiological loading or low level ultrasound.

Progress—To date we have designed and tested several versions of the "piezoplate." Initial tests showed that piezoelectric materials placed on the plate (so as to be in direct contact with bone) were not effective, probably because charge density over the surface was too low. Accordingly, we developed a device in which the piezoelectric material is sealed within the plate and all charge developed is collected and delivered to bone via electrodes. During the past year we have continued to concentrate on electronic and mechanical design considerations necessary to create a prototype that could be used for trials in large animals as a precursor to fabricating an initial model for clinical use. These results have been reported recently in detail (see below). In another series of tests, we showed that an implanted piezoelectric material can be activated by external, low-power ultrasound to generate currents as high

as 1mA following rectification. This study suggests that external ultrasound may represent a practical source of power for implanted bone stimulation devices. In another ongoing series of tests, we are utilizing the well-recognized rabbit tibia model to test effects of ultrasonically generated current on intramedullary bone formation.

Preliminary Results—To date we have determined that (rectified) 20 μ A currents generated by ultrasonic activation of a piezoelectric ceramic have effects similar to battery generated currents but that non-rectified 2.4mHz currents at 20 μ A RMS have no effect.

Future Plans/Implications—Further studies in progress with the rabbit tibia model will determine the effects of non-rectified ultrasonically generated currents at higher levels as well as low frequency currents, as would be generated by physiological loading. Also, we are developing a delayed union model in the radius of large canines and plan to test effects of the piezoelectric plates on altering the natural history of healing of these defects.

Publications Resulting from This Research

Piezoelectric Internal Fixation Devices: A New Approach to Electrical Augmentation of Osteogenesis. Cochran GVB, Johnson MW, Kadaba MP, Vosburgh F, Ferguson-Pell MW, and Palmieri VR, *Journal of Orthopaedic Research* 3(4):508-513, 1985.

Design Considerations in Development of a Prototype Piezoelectric Internal Fixation Plate. Cochran GVB, Johnson MW, Kadaba MP, Vosburgh F, Palmieri VR, *Journal of Rehabilitation Research and Development* 24(2):39-50, 1987.

External Ultrasound Can Generate Microampere Direct Currents In Vivo from Implanted Piezoelectric Materials. Cochran GVB, Kadaba MP, Palmieri VR, Accepted for publication, *Journal Orthopedic Research*.

Effects of Implanted Piezoelectric Materials on Osteogenesis. Cochran GVB, Haboubi A, Palmieri VR, and Kadaba MP, *Proceedings of the 13th Annual Meeting of the Society for Biomaterials*, 150, New York, NY, June 2-6, 1987.

Synthetic Bone Graft Materials in Segmental Defect Fractures

Kenneth D. Johnson, M.D.

Veterans Administration Medical Center, Dallas, TX 75216

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The object of this study is to define the healing parameters of synthetic bone graft substitutes when used in a previously developed canine model of bilateral segmental defect fracture healing. These synthetic bone graft materials are compared to the previously defined ideal bone graft material, autogenous cancellous bone graft.

Progress—Prior work has determined that autogenous cancellous bone graft consistently results in 100 percent solid union. Ground autogenous and allograft cortical bone have been shown to be ineffective in uniting this segmental defect fracture. Several synthetic bone graft substitutes have been used, including calcium hydroxyapatite (HA), tricalcium phosphate (TCP), and a combination of bovine collagen with hydroxyapatite and TCP. These materials were used both with and without additional bone marrow aspirate. Surgery is performed on bilateral dog radii, creating a 2-centimeter defect at the junction of the middle and distal third of the radius. This defect is stabilized with an external fixator. Periosteum is totally excised from the defect, and cancellous bone graft obtained from the contralateral humeral head is placed in one defect while the synthetic bone substitute material is placed in the defect in the other radius. Half of the animals have bone marrow aspiration performed from the ipsilateral humeral head and placed into the segmental defect with the synthetic bone graft material, the other half do not.

After periods of 12 and 24 weeks, the dog is sacrificed, and the radius is studied for mechanical strength as well as histomorphometry. This model allows a controlled study in individual animals. The significance of this study is that bone graft substitutes are increasing in popularity in the United States and other countries. They serve a need to decrease the

morbidity of obtaining autogenous cancellous bone graft used in the segmental defects. The efficacy of these synthetic materials has been shown in metaphyseal defects, which are less stressful and result in more consistent union than diaphyseal defects. There are limited reports demonstrating the efficacy of these synthetic materials in segmental diaphyseal defects without periosteum present.

Preliminary Results—Preliminary findings (clinical evaluation, X-ray, and biomechanical data) demonstrate that hydroxyapatite and TCP without bone marrow aspirate, have little effect in achieving union in segmental diaphyseal defects. Collagen with hydroxyapatite and TCP has an increased ability to achieve union. With the addition of bone marrow aspirate, all materials studied have an improved ability to achieve union. Collagen with HA and TCP plus bone marrow aspirate nearly approaches the effectiveness of autogenous cancellous bone in this model. All animals in this part of the project have been sacrificed. Current work progresses with completion of biomechanical and histomorphometric data on all explanted dog radii.

Future Plans/Implications—Future plans have begun with initiation of the third phase of this project. Several dogs have had prototype variable stiffness external fixators applied to segmental defects and are being evaluated for variables that may need to be improved prior to beginning surgery on multiple dogs.

The first phase of this project will be submitted to the *Journal of Orthopaedic Research* in early 1988. The second phase (synthetic materials) will be submitted to the *Orthopaedic Research Society* for presentation at the 1989 annual meeting.

Noninvasive Assessment of Fracture Healing

R.E. Jones; M.G. Strauss, Ph.D.; K.L. Lawrence, Ph.D.; R.W. Bucholz, M.D.
Veterans Administration Medical Center, Dallas, TX 75216

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Previous work has shown that the impact resonant frequency of normal healing fractured human tibiae increase with healing time. Delayed unions show a resonant frequency versus time healing pattern significantly different than normal healing fractures. The current work discussed investigates the relationship between the resonant frequency and callus strength of 21 osteomized canine radii. A finite element model relating resonant frequency to leg and callus parameters is discussed.

Progress—Twenty-one healthy mongrel dogs in the weight range between 20 and 40 kg underwent unilateral left radius osteotomies. Spoon splints were used to immobilize the bone. Under general anesthetic, each dog was tested for their right and left radius resonant frequencies at weekly intervals. This was accomplished by holding a PCB-303A02 2gm accelerometer against the lateral part of the distal radius and impacting the lateral part of the proximal radius with PCB-208A03 impact hammer. Both signals were processed by an HP5420B Digital Signal Analyzer. From the displayed transfer function, the resonant frequencies were determined. At approximately weekly intervals, a dog was sacrificed and both radii were excised. CT scans of the radius were obtained before the radii were subjected to destructive torsional strength testing. A finite element model of the *in vitro* canine radius was constructed from 19 beam elements and one truss element: the boundary conditions were hinged-free where the truss element approximated a very weak spring at the "free" end. The effect of varying bone length, fracture site, callus geometry, and material properties were investigated.

Results—Left versus right normal radius resonant frequency prior to osteotomy had a correlation of $r = .88$. Modeling each of the dogs's resonant frequency healing curves for those dogs tested more than four times after 20 days post-osteotomy, revealed three types of healing curves. Six dogs had statistically significant positive slopes, two had significant negative slopes and five had healing slopes

judged not significant at the 0.05 level of significance. Of the two dogs with negative healing slopes, one of them was found to have a below-normal callus healing strength, the other demonstrated problems in maintaining fracture alignment early on. The pooled values for the normalized resonant frequencies for all dogs during 20 to 120 days post-injury showed a very significant increasing linear regression at the 0.0001 level of significance, indicating that the normalized resonant frequency increases with healing time. The normalized resonant frequency, NFrequency, is defined as the ratio of the resonant frequencies of the fractured radius over the contralateral normal radius. Similarly for the normalized torsional breaking strength, NStrength.

A linear model was fit to the normalized torsional breaking strength over healing time for the period between 20 and 120 days post-injury, DPI, and was found to be: $NStrength = 0.017 * DPI - 0.191$, $r = 0.86$, $Pr < 0.0001$. Two models relating normalized torsional strength to normalized resonant frequency were developed which indicated that the resonant frequency does give an indication of callus strength.

By using the finite element model, parameters could be varied individually in order to evaluate their effect on the resonant frequencies. After experimental and theoretical validation of the model, the following results were found:

1) The location of the fracture affected the first two resonant frequencies differently. The lowest mode was most sensitive to midshaft fractures and the second mode was more sensitive to proximal and distal fractures.

2) When the modulus of elasticity was varied, both of the first two modes changed parabolically. The resonant frequencies were most sensitive to changes in low modulus. Sensitivity decreased significantly at higher values of Young's modulus.

3) As the callus matures, it slowly calcifies, thus increasing its mass density. The model shows that the change in mass density is insufficient to affect either of the first two resonant frequencies sufficiently to deem it an important variable to follow.

4) Both of the first two modes showed extreme sensitivity to different bone lengths where the longer the bone, the lower the resonant frequency.

The last parameters studied were the combined moment of inertia and the cross sectional area of the callus. It was necessary to model both parameters simultaneously because one cannot separate one from the other in the maturing callus. The computerized axial tomographic images of the dog

calluses were used to determine the cross sectional areas and moments of inertias at different callus ages. This information was then entered repetitively to the FEM in order to determine the resonant frequencies. It was found that both modes are sensitive to changing moment of inertia in that they both increase with an increase moment. The effect is greater on the second mode than on the first.

Enhancement of Wound Healing, Using Synthetic Skin, Electrical Stimulation and Hyperbaric Oxygen Therapy

Kao Su Kung, M.D.

Veterans Administration Medical Center, Lyons, NJ 07939

Sponsor: VA Rehabilitation Research and Development Service (Project #XA447-R)

Purpose—Loss of skin and other connective tissue as a result of either or mechanical pressure is a common problem. It has been estimated that 5 to 30 percent of the hospitalized population experiences loss of skin due to pressure. Several approaches have been developed to enhance healing—including treatment with hyperbaric oxygen, wound dressings, electrical currents, and artificial skin—in addition to surgery.

The purpose of this proposal is to develop a series of parallel studies directed at enhancing rates of dermal and epidermal healing. The short-term goal of this project will be to optimize the rate of dermal and epidermal healing using a collagen-based artificial skin developed at Robert Wood Johnson Medical School. The artificial skin will be studied in different physical forms in the presence and absence electrical stimulation. Our long-term goal is to be able to replace the dermal and epidermal layers of skin with tissue culture grown equivalents.

Specifically this proposal involves studying the enhancement of healing in an animal model and in ulcer patients using a collagen-based material in the presence and absence of a low electrical current. These studies are an extension of preliminary studies conducted in the Biomaterials Center at Robert Wood Johnson Medical School. We will also study the rate of wound healing in an animal model and in ulcer patients with collagen-based beads having

diameters of about 200-1000 μm .

In addition to preliminary animal studies on a porous sheet-like collagen-based material, Drs. Silver and Berg have developed methodology to produce porous beads of this material. This bead-like form needs to be tested in animal models; however, it has potential value in the coverage of wounds that do not have smooth contours. Since most ulcers have "hills and valleys," this form of the collagen-based material would be easier to apply.

The project will be broken into four parts: 1) continued clinical testing of collagen-based material used as a covering for decubitus ulcers; 2) animal and clinical testing of an electrically stimulated collagen-based material; 3) animal and clinical testing of porous collagen-based beads; and, 4) control clinical testing of hyperbaric oxygen treatment.

Results of preliminary clinical studies suggest that the rate of healing of decubitus ulcers treated with a type I collagen-based material is markedly increased even in the absence of fibronectin, hyaluronic acid, and electrical stimulation (Doillon et al., 1987). We propose to further evaluate use of a collagen-based material in the presence and absence of low D.C. electrical current to stimulate healing of full thickness wounds in animals and decubitus ulcers in humans. Our long-term goal is to grow host skin cells on collagen-based material in cell culture for use as skin grafts on humans.

Circulatory and Mechanical Response of Skin to Compression Loading

Frederick A. Matsen, III, M.D.; Theodore K. Greenlee, M.D.; Ernest M. Burgess, M.D.; Craig R. Wyss, Ph.D.; Richard M. Harrington, M.S.

University of Washington; Veterans Administration Medical Center, Seattle, WA 98108 and Prosthetics Research Study, Seattle, WA 98195

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Amputations in the treatment of peripheral vascular disease (PVD) and diabetes present a major challenge in the patient population served by the Veterans Administration. The restoration of gait in these amputees requires loading areas of skin that do not normally sustain weightbearing loads and that may already be at risk due to circulatory compromise. The purpose of this study is to investigate how compression loading of skin produces local ischemia, and how different mechanical properties of the skin and underlying tissues affect this relationship.

The study encompasses four projects: 1) determining these relationships in normal skin subjected to static compression loads; 2) determining these relationships in normal skin subjected to cyclic compression loads; 3) determining these relationships in the skin of patients with PVD and diabetes, as well as in the skin of residual limbs after amputation; and, 4) developing a method for testing patients prior to prosthetic fitting, to determine areas where their skin response to applied compression loads may leave them especially vulnerable to breakdown due to local ischemia.

Progress—The experimental method utilizes transcutaneous partial pressure of oxygen (TcPO₂) sensors to monitor the status of the subcutaneous circulation. Previous investigations in our laboratory have shown that TcPO₂ is a useful predictor of amputation wound healing in patients with peripheral vascular disease. A 22-gauge catheter is placed in the subcutaneous tissue below the TcPO₂ sensor to measure subcutaneous pressure by the infusion technique. Loads are applied directly to the TcPO₂ sensor by an Instron 1122 Universal Testing System and skin displacement is measured by a linear variable differential transformer (LVDT). The average applied pressure is calculated from the applied compression load and the contact area of the TcPO₂ sensor at the skin surface.

We have investigated skin over the anterior crest

of the tibia and over the tibialis anterior muscle 12 centimeters distal to the patella approximating the usual below-knee amputation level in ten normal human volunteers (ages 25-43 years). A range of pressures from 0 to 125 mmHg was applied and the TcPO₂ allowed to stabilize for three minutes. The load was then removed and the TcPO₂ allowed to return to baseline value. Ankle systolic blood pressures were measured with a Doppler flow sensor and ankle pneumatic cuff. The TcPO₂ values were plotted against both the applied pressure and the subcutaneous pressure. Regression analysis was used to calculate the pressure and displacement at which TcPO₂ reached zero. Zero TcPO₂ indicates the point at which the skin circulation has been reduced to the point that the metabolic needs of the skin are just being met and no excess oxygen is available to diffuse through the skin. Any additional pressure beyond this level will begin to produce local ischemia.

Preliminary Results—The following results have been achieved: 1) The skin over bone showed a significantly different load-deformation relationship than the skin over muscle. Initial stiffness for applied pressures less than 20 mmHg over bone was 2.5 times stiffer than skin over muscle. For applied pressures greater than 40 mmHg, skin over bone was 7 times stiffer than skin over muscle. 2) The resting TcPO₂ values for the skin over muscle and the skin over bone were similar for the ten subjects (57 ± 14 mmHg as compared to 61 ± 7 mmHg). 3) The average ankle blood pressures for the ten subjects was 137 ± 10 mmHg. 4) The applied pressure at which the TcPO₂ reached zero was significantly greater for skin over muscle than for skin over bone (74 ± 16 mmHg as compared to 42 ± 8 mmHg, $p < .001$). 5) The subcutaneous pressure at which TcPO₂ reached zero was not significantly different for skin over muscle and skin over bone (31 ± 13 mmHg as compared to 28 ± 10 mmHg). 6) The displacement at which TcPO₂ reached zero

was significantly more in skin over muscle than in skin over bone (5.6 ± 1.0 mm as compared to 1.1 ± 0.3 mm, $p < .001$).

Future Plans/Implications—These results demonstrate that statically applied pressures in normal subjects compromise local circulation as reflected by the TcPO₂ values. Skin over muscle tolerates

higher values of applied pressure than skin over bone before TcPO₂ falls to zero. Similarly, skin over muscle tolerates a higher amount of indentation than skin over bone. Similar experiments will be conducted for cyclically applied loads in normal subjects and then the skin of patients with peripheral vascular disease and/or diabetes will be studied.

Morphologic and Ultrasonic Analysis of Normal and Ischemic Human Wounds

John Olerud, M.D.; George Odland, M.D.; Ernest Burgess, M.D.; Roger Pecoraro, M.D.; Greg Raugi, M.D.; Lloyd Fisher, M.D.; Allen Gown, M.D.

Veterans Administration Medical Center, Seattle, WA 98108

Sponsor: VA Rehabilitation Research and Development Service

Purpose—For the past four years we have engaged in the investigation of deficiencies in the wound healing process in individuals with peripheral vascular disease (PVD) and diabetes mellitus (DM). We hope to identify abnormalities in the repair process which may suggest clinical interventions.

Progress—We have utilized standard incised wounds created with a Simplate II bleeding time device to produce uniform wounds on normal elderly subjects as well as patients with PVD or DM who are awaiting amputation. A variety of time points following wounding have been evaluated. In addition to morphological and immunochemical evaluation of the repair process, we are currently investigating the use of high frequency ultrasound as a method for noninvasive evaluation of the repair process. A scanning laser acoustic microscope (SLAM) is being used for the latter studies.

Results—We have now studied 40 individuals with PVD or DM and ten normal elderly subjects. We have developed a time table for morphological and immunochemical events of repair on the lower extremities of elderly normal subjects and are using those standards for comparative studies in individuals with PVD and DM. We currently have a major interest in assessing the role of nonenzymatic glycosylation in the abnormal repair process for individuals with DM. We have succeeded in immunostaining of tissue sections with a monoclonal antibody specific for the glucitol-lysine linkage which is the site of nonenzymatic glycosylation of proteins. We

are now evaluating the location of nonenzymatic glycosylation in diabetic skin, nerves, and blood vessels as well as wound tissue.

Future Plans/Implications—We hope to be able to use our monoclonal marker for nonenzymatic glycosylation to identify specific cells and perhaps areas in the wound matrix which may be most affected by nonenzymatic glycosylation. This is particularly relevant since it has been shown that nonenzymatic glycosylation specifically affects certain structural and regulatory proteins. Elevated glucose levels affect the function of cells such as neutrophils, monocytes, and fibroblasts. We are also hopeful that we can identify morphologic abnormalities in the repair process by comparing normal elderly subjects with individuals with PVD and DM. Experiments are also underway to assess the utility of high frequency ultrasound in assessing wound maturation. It may be possible to assess abnormalities in the material properties of wounds such as tensile strength and collagen content as well as assessing images which may identify early evidence of wound failure.

Publications Resulting from This Research

Ultrasonic Assessment of Skin and Wounds with the Scanning Laser Acoustic Microscope. Olerud JE, O'Brien W Jr., Riederer-Henderson MA, Steiger D, Forster FK, Daly C, Ketterer DJ, Odland FG, *J Invest Dermatol*, 88:615-623, 1987.

High-Frequency Ultrasonic Imaging and Backscatter Attenuation Techniques for Determination of Thermal Injury to the Skin. Forster FK, Olerud JE, Pomajevich GR, Holmes AW,

Sharar SR, *IEEE Ultrasonics Symposium Proceedings*, 1986.

Reliability of Transcutaneous Oxygen Tension Measurements in Elderly Normal Subjects. Olerud JE, Pecoraro R, Burgess

E, McKnight B, Wyss C, Reiber G, Matsen F, *Scan J Clin Lab Invest* (in press).

Thrombospondin in Early Human Wounds. Raugi G, Olerud J, Gown A, *J Invest Dermatol* (in press).

Altered Collagen and Wound Metabolism in Non-Healing Diabetic Ulcers

Roger E. Pecoraro, M.D.; John Olerud, M.D.; Mary Ann Riederer-Henderson, Ph.D.; Ernest Burgess, M.D.; Frederick A. Matsen, M.D.; Craig Wyss, Ph.D.

Veterans Administration Medical Center, Seattle, WA 98108

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This project is designed to test the hypothesis that potentially correctable metabolic abnormalities may interact with ischemia, neuropathy, and infection to obstruct healing of diabetic ulcers. Subjects include diabetic and nondiabetic patients admitted to the Seattle VA Medical Center Amputation Service who may require lower extremity amputation as a result of diabetes and/or vascular disease. We will test whether recent poor glycemic control, abnormal ascorbic acid metabolism, altered zinc availability to injured tissue, and increased nonenzymatic glycosylation of dermal collagen are associated with, and potentially responsible for, failure of wound healing which leads to amputation in diabetic individuals.

Progress—Fasting plasma glucose and glycosylated hemoglobin measurements estimated glycemic control in diabetic patients. Ascorbic acid levels were measured by high performance liquid chromatography in samples of plasma from all patients and in skin and dermal tissue from selected patients. Zinc levels were measured in samples of plasma, skin, and wound tissue by atomic absorption spectrophotometry. Collagen fractions were extracted from skin and wound tissue specimens from amputated limbs for subsequent measurement of the extent of glycosylation of collagen. Nutritional status was evaluated by a laboratory panel of nutritional indicators. Vascular status of diabetic and nondiabetic amputation subjects has been documented by standardized measurements of limb transcutaneous oxygen tension (TcPO₂) and segmental Doppler blood pressures.

We have studied 82 diabetic individuals who have

received limb amputations. Sixty nondiabetic amputees, all with peripheral vascular disease, have been enrolled. In addition, many of the biochemical and vascular measurements have been standardized in ten healthy non-smoking elderly males without diabetes or vascular impairment. Vascular and plasma metabolic measurements have been made in 220 control diabetic individuals admitted to the same hospital but who have not had amputations or lower extremity ulcers.

Preliminary Results—Both diabetic and nondiabetic amputation patients have shown significant deficiencies in plasma zinc and ascorbic acid levels. Analyses of ascorbic acid and zinc in tissue extracts suggests depleted levels occur in nonhealing ulcer tissue, with depletion more marked with poor diabetic control.

Future Plans/Implications—Further studies are in progress to determine if tissue concentrations of ascorbate and zinc in these patients are suboptimal for adequate wound healing. Experimental iatrogenic microwounds have been inflicted on the limbs of a volunteer subgroup of patients seven days prior to amputation; histologic evaluation of those tissues will provide a semi-quantitative independent index of cutaneous wound healing to correlate versus the metabolic parameters.

The objective of these cumulative investigations is an attempt to identify metabolic abnormalities which are potentially correctable and which may contribute to limb loss and wound failure in diabetic individuals.

Edinburgh Unilateral External Fracture Fixation Device

E.R.C. Draper B.Sc., (Hons) M.B.E.S.

Bioengineering Centre, Princess Margaret Rose Orthopaedic Hospital, Edinburgh EH10 7ED, Scotland

Sponsor: *Lothian Health Board*

Purpose—A new external fracture fixation device is being developed in conjunction with the Department of Orthopaedic Surgery of the University of Edinburgh. It is designed to be simple, highly adaptable, and easy to apply. It is also possible to vary the axial stiffness from being rigid, to being completely free in the axial direction, while any other movement is prevented. Incorporated into the design is the ability to monitor the mechanical properties of the fracture site and so allow the healing to be monitored, which should give a clearer indication as to when to remove the fixator or to give an early indication of late or non-union.

Progress—The fixator is manufactured in stainless steel: the bar is 420 mm long and 22 mm in diameter,

and uses 4.8 mm diameter pins. The pin clamps have an adjustment of 360 degrees about all three axes, so that they can be mounted anywhere along the length of the fixator bar or pin and have an adjustment of 10 mm in a direction perpendicular to the bar and pin.

Preliminary Results—The initial testing of this device shows that it is mechanically robust enough to withstand all normal loads which it will be expected to withstand throughout the fracture management.

Future Plans/Implications—Once the device has been fully tested, it will be evaluated clinically. It is hoped that the fracture monitoring will be useful as soon as it is started.

Enhancement of Ulcerated Tissue Healing by Electrical Stimulation

L. Vodovnik, D.Sc.; A. Stefanovska, Dipl. Eng.; R. Turk, M.D.; H. Benko, P.T.; A. Kolenc, Dipl. Eng.; M. Maležič, Dipl. Eng.

E. Kardelj University, University Rehabilitation Institute, Jožef Stefan Institute, 61000 Ljubljana, Yugoslavia

Sponsor: *National Institute on Disability and Rehabilitation Research; Slovene Research Community, Ljubljana, Yugoslavia*

Purpose—The association of endogenous currents with healing processes has led to considerable efforts to enhance soft tissue healing by exogenous currents. However, obtaining the quantitative data and statistical analysis of the results is complicated, due to the variety of pathophysiological and physical factors involved in wound healing processes. In the *Rehabilitation R&D Progress Reports - 1986* we presented the decrease in size after application of electrical stimulation of all treated wounds. Progress had been made toward the evaluation of the effects of electrical stimulation compared to those obtained in the control group.

Progress—The stimulation technique is the same as described in our previous progress report. The volume of the wound was measured once weekly by measuring its surface and depth and wound surface was approximated by an ellipse. Additional

data was obtained by photographing the wound surface. The data of the surface was stored by means of a digitizing tablet after projection of the slides. CAD program was used for entering the shape and calculation of the skin area. Twelve spinal cord injury patients with fifteen decubitus ulcers were included in the study. Seven of them, with nine ulcers, were treated by electrical stimulation. Five other patients with six ulcers were included in the control group. For four weeks the wounds were treated by conventional methods and measured once weekly. After this period, electrical stimulation was added to these patients as well. The patients had developed these wounds over several weeks (from 2 days to 86 weeks).

Results—The healing process, once triggered by electrical stimulation, has an exponential behavior. During the study, it became clear that consistent

evaluation of the results required not only careful distinction between the patient population, but also between the location of the observed wound. The estimated values of the time constant are 4.7 ± 0.9 weeks for sacral wounds and 2.4 ± 0.4 for trochanter

wounds. Time-histories of wounds treated by conventional treatment are rather constant, however, and at present a lack of data has not allowed an estimation of the time constant with statistical significance.

Acceleration of Fracture Healing by Electrical Fields

Carl T. Brighton

University of Pennsylvania, Medical Education Building, Philadelphia, PA 19104

Sponsor: National Institutes of Health

Purpose—The object of the proposed research is to continue to investigate the stimulation of fracture healing with a capacitively coupled electrical field and to determine the mechanisms of action of electrically induced osteogenesis. The proposed research is designed 1) to determine the most efficient duty cycle in applying a capacitively coupled electrical signal to stimulate fracture healing in an osteotomized rabbit fibula model, and 2) to determine the mechanism(s) for electrically induced osteogenesis by evaluating a) the microenvironmental changes (pO_2 , pH) occurring in the vicinity of a cathode, b) possible responding cells (bone cell, capillary endothelial cell, pericyte, and polymorphic cells), and c) intracellular calcium, cyclic AMP, and prostaglandin (PGE₂).

Methods to be used include:

- 1) histologic, roentgenographic, and mechanical testing of osteotomized rabbit fibula;
- 2) mathematic modeling using finite element analysis to calculate electric fields in rabbit fibula callus;
- 3) microscopic morphologic digitabilization (Zeiss MOP-3) of newly formed bone in the vicinity of a cathode in the rabbit tibial medullary canal;
- 4) needle electrode determination of pO_2 and pH of medullary canal in the vicinity of an active

cathode;

5) Coulter cell counting, S35 and C14proline uptake, and collagen typing of isolated rat calvarial bone cells, calf brain capillary endothelial cells and pericytes, and rabbit tibia post-traumatic polymorphic cells exposed to various capacitively coupled electrical fields;

6) histologic examination and collagen content and typing of bone cells, endothelial cells, pericytes, and polymorphics grown in Algire diffusion chambers placed within the rabbit tibia medullary canal and exposed to direct current;

7) electron microscopic evaluation of the role of the polymorphic cell as an osteoblast precursor cell and of the role of the endothelial cell and pericyte as possible origins of the polymorphic cell and correlating these findings with histologic staining for factor VIII, antismooth muscle actin antibody, and for alkaline phosphatase; cAMP, prostaglandin, and intracellular ionized calcium changes induced by an electric field;

8) Fura 2 fluorescence and quantitative digitized fluorescent microscopy to determine the relationship of chondrocyte intracellular calcium to matrix mineralization in the fracture callus.

A Study on Disintegration of Carpal Bones in Leprosy

S.B. Sane, M.S.; V.N. Kulkarni, B.Sc.(PT)PGDR; R.C. Sharangpani, M.S. Dip. Sports Medicine; J.M. Mehta, M.B.B.S.

Dr. Bandorawalla Leprosy Hospital, Kondhawa, Pune 411022, India

Sponsor: Poona District Leprosy Committee

Purpose—Visibly deformed and disorganized wrists were observed in some of the advanced cases of

tarsal disintegration (TD) with bad foot ulcers and amputation. Three patients admitted that they were

using their disintegrated limbs to get up from the ground or to walk for many years. These patients had gross structural abnormality of the carpus. Carpal disintegration (CD) results from compressive and shearing forces transmitted across the wrist of a neuropathic hand of leprosy super-imposed on the carpal architecture already weakened by the ligamentous attenuation following infection, osteoporosis, fracture, etc. It may manifest itself as a "wrist-sprain" in early stages or as a grossly disorganized swollen wrist-joint with total loss of normal configuration and bony architecture in late stages. The possible sequence of events in the occurrence and progression of CD can be described in two stages. 1) A patient may neglect minor fractures, sustained due to lack of pain. Hence, a haematoma forms and the joint space increases due to this effusion, resulting in a haemarthrosis. 2) There is calcification in the clot, articular surfaces become irregular and sclerotic and the joint capsule becomes lax followed by subluxation or dislocation.

As in any neuroarthropathy, early detection and arrest of the process is an essential requirement in treating the ailment. The purpose of this study was to devise a radiological method to detect the early carpal involvement. A method of measurement of carpal height ratio (CHR) has been suggested.

Progress—In the initial study, we found three cases

of advanced CD in patients whose wrist-joints were subjected to the trauma of weightbearing. With this in mind we examined the dominant wrists of high risk patients both clinically and radiologically.

The following high risk groups of patients were studied: 1) patients compelled to bear weight on the hand while getting up from the ground; and, 2) patients with a history of repeated sub-clinical trauma to the wrist-joint (such as those engaging in sports or heavy manual labor). X-rays (posterior-anterior P/A view) of the dominant wrists of these patients were taken and CHR was studied. (CHR is expressed as L_2/L_1 where L_2 is the Carpal Height and L_1 is length of 3rd M.C.; normal value being 0.54 ± 0.03 . The Carpal Height or L_2 is the distance from the base of 3rd M.C. to the distal articular surface of radius, measured on P/A X-rays along the projected longitudinal axis of 3rd M.C. It is constant in the normal wrist in all positions of ulnar and radial deviation, when the deviation occurs in fixed plane).

Results—Twelve high risk patients were studied. Upon examination and calculation of CHR in these patients, 2 had early CD, 5 were borderline for CD and 5 were normal. The patients were kept under observation. Those with borderline CHR were advised a change of job, rest with plaster, etc. In some cases, CHR over a period of time was helpful in diagnosing slow progressive destruction.

Graded Weightbearing in Tarsal Disintegration in Leprosy

P.C. Sharangpani, M.S.; Dip. Sports Medicine; V.N. Kulkarni, B.Sc.(PT)PGDR; S.B. Sane, M.S.; J.M. Mehta, M.B.B.S.

Dr. Bandorawalla Leprosy Hospital, Kondhawa, Pune 411022, India

Sponsor: Poona District Leprosy Committee

Purpose—As in osteoporosis, the bony changes such as cystic cavities, are part of the disease in leprosy. For patients undergoing immobilization for ailments like tarsal disintegration tibialis, posterior transfer surgery or fractures of the lower limb and other soft tissue injuries add to the problem of osteoporosis inherent in the disease.

The tarsal disintegration (TD) process results in the destruction of the architecture of the bones along with the loss of bony matrix. With rest the healing processes predominate and the architecture is partially restored, but not strictly according to the

weight transmission lines. Immobilization itself precludes bony matrix formation. Early and improper weightbearing leads to reversal of the process of healing or an outright fracture of the disintegrated tarsals in the neuropathic foot. In such cases proper stimulus for laying of bony matrix in weight transmission lines can come only through graded weightbearing (GWB). It is with this aim that for the first time this method of weightbearing has been tested in the neuropathic foot of leprosy.

Progress—Twenty-five patients with TD and tibialis

posterior transfer surgery were studied. In cases with severe involvement of tarsals, GWB was instituted at the end of the prolonged immobilization. In early cases of TD the GWB was started after the subsidence of clinical signs such as swelling, etc. GWB was commenced three weeks after the removal of plaster for tibialis posterior transfer surgery patients.

Taking advantage of the preserved proprioceptive and pressure sensations, the patients were asked to record the weight of the diseased foot. They practiced until they could reproduce the same weight without looking at the weighing scale. Patients then walked on crutches exerting no more than the recorded weight on that limb. Gradually the weight on the diseased limb was increased (every two to three weeks depending on clinical and radiological parameters). GWB was ended when patients could bear their full body weight on the diseased limb.

Results—All the cases had good results. They were followed for a period of six months to one year and were found to have stable lesions. They maintained good trabecular patterns (confirmed by X-ray) as compared to the time of completion of GWB. The area of the foot print (taken on a Harris Mat at every stage, i.e., percentage of weight of GWB) was calculated to show the relation of the Graded Weight to the area of the foot and pressure (weight per unit area). GWB increased with weight. The pressure in gm./Sqcm also showed a gradual increase with every stage of GWB.

Thus, it seemed that the body adapted to the sub-maximal stress of GWB and rehabilitation proceeded smoothly. GWB acted as a stimulus to the spatial structuring of the bony trabeculae in the lines of stress. The therapists and patients are confident about the rehabilitation with GWP over partial weight-bearing as the arbitrariness of the latter is eliminated.

XI. Muscles, Ligaments, and Tendons

A. General Properties of Muscle

Decomposition Analysis of the Surface Electromyogram

Kevin C. McGill, Ph.D.; Leslie J. Dorfman, M.D.; Jane E. Howard, M.D.; Erik V. Valainis

Veterans Administration Medical Center, Palo Alto, CA 94304 and Department of Neurology, Stanford University School of Medicine, Stanford, CA 94305

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Diagnostic clinical electromyography (EMG) involves analysis of myoelectric signals recorded using intramuscular needle electrodes. The use of surface electrodes rather than needles would be less painful and more easily accepted by many patients, especially children. However, surface recordings are generally considered unsuitable for electrodiagnosis because of the attenuation and distortion imposed on the myoelectric signals by the subcutaneous tissues and skin.

Recently, it has been shown that an array of small surface electrodes configured as a spatial filter is capable of overcoming some of this distortion. We are interested in developing methods to analyze surface-recorded signals, and in particular to decompose them into their constituent motor-unit action potentials (MUAPs), whose configurational properties, firing rates, and conduction velocities can then be estimated.

Progress—In some superficial muscles, such as abductor pollicis brevis, signals suitable for decomposition can be recorded differentially from a pair of small, closely spaced electrodes. In other muscles, such as brachial biceps, better selectivity can be obtained by forming a linear combination of the signals from an array of electrodes (spatial filter). An array of electrodes can also provide multiple channels of data.

We have experimented with two types of electrode: sharp pins that protrude from a plastic holder just enough (1 mm) to pierce the outer keratin layer of the skin, and flat metallic pads 2 mm square used

on dry skin without electrode paste. The pin electrodes have low impedance (200 kilohms) and good selectivity, resulting in less noise, quieter baselines, better common-mode rejection, and signals twice as large and with sharper rise times than those recorded by pads. The pad electrodes exhibit high impedance (> 2 megohms) and high noise (10 μ V rms), but are completely noninvasive. Signals from either pads or pins can be amplified using a conventional electromyograph.

The surface EMG can be analyzed using a method, called automatic decomposition electromyography (ADEMG), that we previously developed to analyze needle EMGs. Surface EMGs suffer from the loss of high-frequency detail, which makes MUAPs less distinctive from one another and hence more difficult to identify. This can be compensated to some extent by the additional information in a second channel. Two channels also allow estimation of the MUAP conduction velocity, based on the latency between MUAP arrival times at the two pickup points.

Preliminary Results—Our preliminary studies point to the feasibility of using surface recordings for diagnostic EMG. We have been able to decompose EMGs from abductor pollicis brevis and brachial biceps, yielding MUAPs with shapes and firing rates not unlike those seen with needle electrodes, and with conduction velocities similar to those reported in the literature.

Future Plans/Implications—Future work will involve refining the electrode design and tailoring the ADEMG algorithm for the special characteristics of the sur-

face signal. This approach to noninvasive quantitative EMG may have important application in the electrodiagnosis of neuromuscular disorders.

Automatic Decomposition of the Electromyogram

Kevin C. McGill, Ph.D.; Leslie J. Dorfman, M.D.; Jane E. Howard, M.D.; An Huynh, M.S.

Veterans Administration Medical Center, Palo Alto, CA 94304 and Department of Neurology, Stanford University School of Medicine, Stanford, CA 94305

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Automatic decomposition electromyography (ADEMG) is a computerized method for decomposing electromyographic (EMG) interference patterns into their constituent motor-unit action potentials (MUAPs) so that the configurational and behavioral properties of the MUAPs can be quantitated. ADEMG offers three advantages over traditional analysis of single MUAPs recorded during weak muscular contractions: the ability to process large numbers of MUAPs efficiently, the ability to analyze later-recruited as well as first-recruited MUAPs, and the ability to measure firing-related as well as shape-related MUAP properties.

Progress—We have measured the configurational and firing properties of 16,000 MUAPs from the brachial biceps, triceps, and anterior tibial muscles in 35 normal individuals in three age groups (20-40, 40-60, and 60-80 years old). Recordings were made during stable isometric contractions at threshold, 10 percent and 30 percent of maximum voluntary contraction, using standard concentric and monopolar needle electrodes. The MUAP properties were analyzed to determine the effects of contractile force, muscle, age, gender, and electrode type.

Results—In all muscles, increased contractile force was associated with significantly increased mean MUAP amplitude, rise rate, number of turns, and firing rate; and with significantly decreased mean MUAP duration, due to noise-dependency of the duration measurement. These results demonstrate that contractile force is a major determinant of MUAP shape and behavior properties and so must be measured or controlled in clinical EMG studies. These findings also lend support to the size principle of motorneuron activation.

Publications Resulting from This Research

Decomposition Analysis of the Surface Electromyogram. McGill KC, Dorfman LJ, Howard JE, Valainis E, *Proc. 9th Ann Conf IEEE Eng Med Biol Soc*, 1987.

Most mean MUAP properties differed significantly between muscles, pointing up the need for separate normative databases for each muscle. Mean MUAP amplitude, duration, and numbers of turns increased linearly with age, suggesting an ongoing process of progressive denervation and compensatory reinnervation. Mean MUAP firing rates decreased with age. In a subgroup of 12 age-matched gender pairs, men had larger mean MUAP amplitudes, rise rates, and numbers of turns, probably reflecting larger muscle-fiber diameters.

Mean MUAP amplitudes, rise rates, and numbers of turns were significantly greater when recorded with monopolar electrodes, while mean MUAP duration and firing rate did not differ significantly. These findings indicate that it may be acceptable to generalize normative data on MUAP duration from one electrode type to another, but that MUAP amplitudes and complexities require independent normative databases (or valid transformations).

Because ADEMG can analyze EMGs too complex to be decomposed by hand or by other computer programs, we have also investigated ADEMG's performance using computer simulations. We simulated EMGs of various complexities and noise levels using MUAPs from normal subjects. The results indicate that ADEMG typically identifies more than 50 percent of the MUAPs in a train with few misidentifications. Estimates of MUAP amplitude, rise rate, number of turns, and firing rate had standard errors of less than 2 percent while estimates of duration had standard errors of up to 20 percent. These findings validate ADEMG's identification and estimation algorithms and point out the difficulties inherent in estimating properties of MUAPs from forceful contractions.

The Myoelectric Signal Decomposition Technique

Carlo J. De Luca, Ph.D., and Daniel Stashuk, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Purpose—The myoelectric signal decomposition procedure was developed by C.J. De Luca in the 1970s to study the individual behavior and interactions of populations of concurrently active motor units. The procedure consists of three parts: signal detection, acquisition, and decomposition. Individual motor unit information is obtained by a detailed analysis of the myoelectric signals detected by highly selective indwelling electrodes during muscle contraction.

Progress—Further refinement of this technique has continued since its initial development, and most recently has concentrated on increasing the speed and ease with which the analysis can be performed. Improvements of this nature have included an alternate electrode configuration better suited for the detection of myoelectric signals of suitable complexity, signal quality monitoring during signal acquisition to ensure stable myoelectric signals for high-yield decomposition, and modification of the decomposition algorithm to reduce and improve operator interaction and to maintain decomposition accuracy. Techniques for the combination of temporal information with the more classical morpho-

logical information used clinically are currently under development. Further improvements to the procedure involving initial template recognition and real time data acquisition are in the planning stages.

Results—Work in this area, however, has not been limited to refinement of the decomposition procedure; it has also included investigation of a number of motor-unit control questions. For example, using the motor unit analysis technique, a study of the phenomenon of synchronization of motor unit activity has been conducted. The effects of specific movement disorders on motor control schemes are also being examined. Changes in motor unit behavior due to the loss of skin sensory input are being investigated, as is the role of muscle function and co-contraction in the existence of common drive for motor unit pools of separate muscles. Myoelectric signals concurrently detected using several different myoelectric signal detection techniques from a common muscle volume are being combined with the decomposition technique to improve our understanding of myoelectric activity and signal composition at different levels of force and throughout prolonged, sustained contractions.

Surface Electrode Design

L. Donald Gilmore, A.B.E.E.; David Casavant, M.S.; Mark Emley, B.S.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Purpose—Clear and accurate detection of myoelectric activity of a muscle from the surface is a basic prerequisite for the comprehensive evaluation of muscle behavior. Most of our laboratory and clinical evaluations require some type of surface electrode to observe muscle signal properties such as amplitude, spectral shift, conduction velocity, and location of motor points. These parameters are useful in evaluating the status of an actively contracting muscle.

Progress—Over the past few years, we have developed several configurations of active surface electrodes that do not require the use of conductive paste or gels. Each electrode configuration is based around an electronic circuit containing a high-impedance, low-noise, differential preamplifier housed in small, rugged, epoxy packages. (A detailed description of the active surface electrode concept appears in the NMRC 1983 *Activities Report*.) We have found that these surface electrodes have the me-

chanical and electrical stability necessary for reliable and consistent low-noise myoelectric recordings. We now use these "standard" electrodes in a vast majority of our laboratory experiments, such as those concerning muscle fatigue. During the past year, thirty additional electrode units were produced in the Electronics Laboratory.

Results—To facilitate surface electrode attachment to large muscle groups which can be particularly

difficult to secure reliably, we are investigating specialized conductive adhesives to hold the electrodes in place. These adhesives play the dual role of firmly securing the electrode to the skin and acting as an electrical contact surface used to detect the myoelectric activity. These additional features will enable the research to position quickly and reliably an array of electrodes on larger muscles such as those of the lower back.

Myoelectric Signal Quality Analyzer

L. Donald Gilmore, A.B.E.E., and Daniel Stashuk, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Purpose—To enhance the clinical applicability of the current myoelectric signal decomposition technique, several steps have been taken to improve the process of signal acquisition. During the past year, refinements in the design of the multichannel needle electrodes, coupled with construction of a new signal-quality analyzer, allowed the investigator to select the optimal electrode location necessary for accurate signal decomposition.

The signal-quality analyzer continually monitors the slope and amplitude of the myoelectric signals detected by the needle electrode during the experiment. The signal's slope and amplitude were chosen to categorize its waveshape and to determine if the waveshape falls within acceptable limits required for accurate decomposition.

The bar graph displays located on the front panel of the instrument indicate the instantaneous slope and amplitude of detected signals together with their adjustable setpoint limits. The device is designed to be rack mounted or the displays may be separated from the main unit and positioned close to the experiment. In this way, the instrument provides the necessary visual and audio feedback to the investigator to select the optimal position of the needle electrode. All outputs from the instrument are designed to be compatible with the existing acquisition hardware of the decomposition system's computer. The signal-quality analyzer will facilitate the usefulness of our decomposition techniques in both clinical and laboratory investigations.

The Frequency Response of Skeletal Muscles: Dependence on Control Strategies and Fiber Types

M. Solomonow, Ph.D.

Louisiana State University Medical Center, New Orleans, LA 70112

Sponsor: *National Science Foundation*

Purpose—The correct frequency response model of a single skeletal muscle has been a longstanding problem. Only unphysiological control inputs (firing rate) could be used or alternate analogue models that preassumed the interaction mode of firing rate and recruitment (which were unknown until recently) could be used.

Progress—We tested the soleus (slow twitch) and m. gastrocnemius (fast twitch) under several physiological control strategies with the aid of our newly-developed stimulation system.

It was shown that the frequency response model consists of a second order system with double poles at 1.8 Hz. This was independent of the control

strategy used, the predominant muscle fiber type, or the force perturbation level. A pure time delay differentiated the models for fast and slow twitch muscles, being 11 msec and 16 msec, respectively.

Preliminary Results—Firing rate control input was reaffirmed to result in a nonlinear model as previously described in the literature.

Skeletal Muscle Reaction to Immobilization

P.A. Huijting; R.H. Rozendal; H. Heslinga; G.J. van Ingen Schenau; M.F. Bobbert

Department of Functional Anatomy, Faculty of Human Movement Sciences, The Free University, Amsterdam, The Netherlands, 1007MC

Sponsor: *None Listed*

Purpose—The purpose of this study was the prediction of reaction of human skeletal muscle to immobilization in various conditions regarding length, duration of immobilization period, and position of the limbs.

Progress—A muscle model, relating architecture of the skeletal muscle to its functional capacity, was formulated and experimentally determined on rat calf muscle and various others.

Application on human calf muscle, using morphological data of human cadavers has been done. The model was also applied in a description of muscular growth. Now it is used in analyzing the effects of various periods of immobilization in different positions, leading to differing muscle lengths.

The work is part of a program on “form, function and coordination of skeletal muscles,” in which it

is tried to relate experimental analysis of animal muscular function to real life human movements in vertical jumping and running.

Preliminary Results—Reaction of muscles to immobilization is very complex and not only varies with muscular position between stretch and shortening, but also varies within the muscle belly, altering architecture, functional capacity, and properties of the contractile tissue.

Future Plans/Implications—During the next year, varying modes of immobilization and their effects on muscular fibers (length, number of sarcomeres, type) and their position in the muscle belly will be studied. Next, interaction of these processes and growth (hypertrophy) will be induced and analyzed.

B. Muscle Contraction

Decomposition of Surface-Detected Myoelectric Signals

Daniel Stashuk, Ph.D. and Carlo J. De Luca, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Purpose—A procedure for the partial decomposition of surface-detected myoelectric signals has been developed. Myoelectric signals are simultaneously measured by selective surfaces of a needle electrode, the cannula, and a nearby surface electrode. A data collection-compression routine digitizes and acquires epochs of the selective needle signals containing motor unit action potentials (MAUPS), while

the cannula and surface signals are continuously digitized and stored. The selective needle signals are decomposed into their component motor unit action potential trains (MUAPTs). The extracted MUAPTs are used to ensemble-average the cannula and surface-detected signals resulting in estimates of some of their constituent MUAPs. The MUAP estimates, and their respective MUAPT, are used

to decompose partially the cannula and surface myoelectric signals.

Results—The results of the data analysis reveal the potential for using the technique to investigate specific myoelectric phenomena. The size of the cannula and surface macro potentials are dependent on the size of the contributing motor unit and its proximity to the detection surfaces. Information on cannula

and surface signals allows the study of size and distance effects. Although the amount of data analyzed is limited and the proportion of cannula and surface signals accounted for is small, the technique has been demonstrated to work and yield information that, upon further analysis, should augment our understanding of myoelectric activity and signal phenomena.

Muscle Force Output During Voluntary Contractions

Giselle Gomez, M.S.; Daniel Stashuk, Ph.D.; Carlo J. De Luca, Ph.D.
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Purpose—This research effort focused on the study of fluctuations in the force output of the first dorsal interosseous, bicep, tricep, deltoid, tibialis anterior, soleus, and gastrocnemius/soleus muscles in healthy humans.

Progress—Subjects generated constant-force contractions at 20, 30, 60, and 80 percent of maximal voluntary effort. The signals analyzed were the deviations of the force signals from their means. Spectral and temporal analyses and quantification techniques were performed on the force-fluctuation signals. The signals were quantified by calculating the mean square value of the force fluctuations. Statistical analyses were performed on the results. The quantified fluctuations were then analyzed to examine their relationship to the function, fiber typing, and size of the different muscles.

Results—This study demonstrated that as the magnitude of the mean force increased, so did the

magnitude of the force fluctuations. Spectral analysis revealed that the majority of the energy of the force fluctuations was below 5.0 Hz. The force fluctuation was separated into two components: extrinsic and intrinsic. The two components correspond respectively to the 0.1–0.8 and 0.8–13.0 Hz frequency bands. The extrinsic component is thought to be due to intentional effort by the subject to correct the force output. The extrinsic component is not a function of fiber type, function, or size of the muscle. The intrinsic component was found to be independent of muscle function. Fiber typing alone was not related, but when discussed in unison with the recruitment properties of the muscles, it does explain changes in the behavior of the force fluctuations. There exists a relationship between the size of the muscle and the intrinsic component. When the number of motor units increased, the intrinsic normalized deviation decreased in an exponential fashion.

Cross-Talk Between Myoelectric Signals of Adjacent Muscles

Roberto Merletti, Ph.D., and Carlo J. De Luca, Ph.D.
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Progress—Surface myoelectric signals were detected from the skin surface above the tibialis anterior muscle, the peroneus brevis muscle, the soleus muscle, and the tibial bone during selective

maximal electrical stimulation of the tibialis anterior muscle in 12 normal subjects. The double-differential technique developed by Broman, Bilotto, and De Luca (1985) was used to determine that the detected

signal was due to volume conduction from the tibialis anterior fibers. The ratios between peak-to-peak values (PP), average rectified values (ARV), and root mean square values (RMS) of the detected M-waves were used as cross-talk indices. The values ranged from 4.8 to 33.0 percent (PP), 4.7 to 36.0 percent (ARV), and 7.7 to 37.4 percent (RMS) for the tibial bone area; from 4.0 to 20.0 percent (PP), 3.5 to 10.0 percent (ARV), and 3.0 to 8.0 percent (PP), 3.4 to 9.1 percent (ARV), and 2.0 to 9.8 percent (RMS) for the soleus muscle area. Neither peak-to-peak values, average rectified values, nor root mean

square values appeared to be correlated with leg size.

Results—It is concluded that a surface myoelectric signal detected on the skin above a muscle and having an amplitude of up to 17 percent of a signal detected above a neighboring muscle may be due to cross-talk rather than to activation of the muscle below the electrode.

A manuscript describing this work is in preparation.

Synchronization of Motor Unit Discharges

Daniel Stashuk, Ph.D.; Carlo J. De Luca, Ph.D.; Jerry Scala, B.S.
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Purpose—Synchronization of motor unit discharges is the tendency for pairs of motor units to contract with preferred latencies relative to each other, more often than would be expected if the motor units were functioning independently. A study of the interdependence of concurrently active motor units was performed.

Progress—Myoelectric signals were detected from healthy subjects during voluntary isometric contractions using a selective indwelling electrode configuration. The signals were decomposed into their constituent motor unit action potential trains (MUAPTs). Pairs of MUAPTs were then analyzed to determine if any interdependence existed. Histograms were created of the time intervals between the firing of a triggering or conditioning motor unit to the subsequent firing of the alternate or conditioned motor unit of a pair. Assuming the motor unit pairs are operating as independent Gaussian point processes, the histograms should be flat with an approximate expected value dependent on the histogram bin width and the mean firing rate of the conditioned motor unit. Bins containing 1.96 standard deviations more than the expected number of

occurrences indicated a 95 percent confidence level statistically significant interdependence or synchronization.

Results—Synchronization measurements of motor units studied in the human first dorsal interosseous (FDI), deltoid, and tibialis anterior (TA) muscles during a variety of force protocols indicate that more than 60 percent of the motor unit pairs examined exhibited synchronization. The latency of the maximum was most often within ± 5 ms and had an average width of approximately 4 ms. The deltoid had lower amounts of synchronization than the FDI and TA muscles, which had similar levels. Synchronization was not found to be a function of contraction level in the deltoid or FDI. The analysis of motor units in synergist and antagonist muscle pairs revealed interdependence within but not across the muscles.

The results of this study were presented in September 1986, at the 33rd Annual Meeting of the American Association of Electromyography and Electrodiagnosis in Boston, and in November 1986, at the 16th Annual Meeting of the Society for Neuroscience in Washington, D.C.

The Common-Drive Principle of Motor Unit Control

Gary Kamen, Ph.D.; Daniel Stashuk, Ph.D.; Sandra Solar, B.S.; Carlo J. De Luca, Ph.D.
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: National Institute on Aging; Liberty Mutual Insurance Company

Purpose—The NeuroMuscular Research Center has previously described a principle of motor unit behavior called *common drive*, which states that the nervous system controls the firing rates of homonymous motoneurons in a tightly coupled manner. Slight increases or decreases in firing rate of one motor unit are accompanied by like changes in other motor units.

Progress—In an experiment conducted in the Motor Unit Laboratory, subjects performed submaximal isometric contractions of the first dorsal interosseous (FDI) and tibialis anterior (TA) muscles while motor unit activity was recorded by a specially designed quadrifilar needle electrode, amplified, and then

stored on FM tape.

Results—Off-line decomposition of the signal into constituent motor unit action potentials revealed a high degree of cross-correlation of the motor units in the TA and in the FDI. There was a tendency toward higher cross-correlation between the motor units of the FDI and those of the TA. In previous research, it has been demonstrated that common drive exists in muscles that are coactivated and functionally related. These new data suggest that coactivation is not a sufficient condition for the existence of common drive. Rather, a common functional relationship between active muscles also appears to be necessary.

Exercise-Induced Adaptations of Skeletal Muscle Grafts

Timothy P. White

University of Michigan, Ann Arbor, MI 48109

Sponsor: National Institutes of Health

Purpose—Many characteristics of skeletal muscle grafts, including mass, functional cross-sectional area, maximum tension development, and oxidative capacity, remain below control muscle values. These deficits potentially limit the usefulness of the graft to the host organism in tasks requiring strength or endurance. In addition to transplantation, the degeneration of skeletal muscle fibers occurs following a variety of diseases, trauma, and excessive physical exercise (especially if lengthening contractions occur). Regardless of the insult inducing degeneration, regeneration of muscle fibers appears to follow a common pathway.

The objective is to determine the effects of the intensity and duration of chronic exercise on the structure and function of free and of vascularized skeletal muscle grafts. In free grafts, the muscle will spontaneously revascularize and muscle fibers will degenerate and new fibers will regenerate. In vascularized grafts, the fibers survive. In both grafts, the fibers show a large functional deficit compared

to control muscle. Hindlimb muscles will be grafted orthotopically in rats. Chronic physical activity patterns will be changed by daily running on a motor driven treadmill and by ablation of muscles synergistic to the graft. It has been well documented in normal muscle, and there are limited data on grafts, that chronic exercise of the appropriate intensity and duration can increase variables which show a deficit in grafts relative to control values. The change of activity will start at 28 days postgrafting and grafts will be studied through 112 days. The capability of different chronic activity patterns to alter growth in grafts that differ as to fiber type and anatomical site will be investigated.

Outcomes will be evaluated by morphological (gross dimensions, histochemistry), biochemical (protein concentrations, protein turnover, metabolic marker), and physiological (contractile properties) techniques. Physical exercise is a complex stimulus to skeletal muscle in terms of the type of contraction, the tension development during contraction, and the

frequency, intensity, and duration of exercise sessions. Resolution of these complexities will provide the scientific basis for establishing postgrafting procedures to improve the structure and function of

grafts in humans and in the rehabilitation of muscles in which some fibers have regenerated due to disease, trauma, or excessive exercise.

Motor Control in Subjects with Clinical Disorders

Joseph F. Jabre, M.D.; Daniel Stashuk, Ph.D.; Carlo J. De Luca, Ph.D.
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *VA Outpatient Clinic, Boston, MA; Liberty Mutual Insurance Company*

Purpose—This study has focused on using the known statistical behavior of motor units in muscles of normal subjects as a basis for comparison with motor unit activity observed in subjects with different clinical disorders, as a means for developing new clinical diagnosis procedures.

Progress—Myoelectric signals were acquired from the first dorsal interosseous muscle of several patients with different clinical disorders. The myoelectric signals were then decomposed, and the resulting motor unit behavior information analyzed. The existence of common drive and the relationships between motor unit firing rates and recruitment levels as functions of percent maximal voluntary contrac-

tion were specifically addressed and compared to normal subject population results.

Results—Progress has been steady but slow. To date, subjects with cerebellar atrophy, ulnar nerve neuropathy, and syringomyelia or liquid-filled spinal cavity have been studied. It has been observed that for the most part the common drive of motor units in these subjects has been preserved. The patient afflicted with syringomyelia appears to have a compressed range of motor unit firing rates when compared to a normal subject performing similar contractions. Further study of the data collected from these subjects and others is ongoing.

C. Muscle Fatigue

Muscle Fatigue and Back Pain

Serge H. Roy, M.S.; David Casavant, M.S.; L. Donald Gilmore, A.B.E.E.; Carlo J. De Luca, Ph.D.
NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *VA Rehabilitation Research and Development Service; Liberty Mutual Insurance Company*

Purpose—As many as 75 million Americans now suffer from severe lower-back pain and each year 7 million more people develop this problem. Despite the many millions of dollars spent on innumerable treatments for the back, the majority of patients have chronic, remitting symptoms. Improved methods for assessing back disorders could help to diminish the problem and the financial burden of this disabling condition.

Progress—We have begun to develop and implement a technique to provide the clinician with an objective

index with which to measure treatment outcome for lower-back musculature. This technique estimates the fatigue rate of contracting muscles by measuring the shift occurring in the frequency spectrum of the surface-detected myoelectric signal. The dynamic interaction of synergistic back muscles during fatiguing contractions can be represented by "fatigue patterns" created by the frequency shifts occurring in different muscles. Differences in these patterns associated with lower-back disorders may represent functional disturbances in back muscles.

In preparation for implementing this technique,

we have designed and constructed a restraining device to stabilize the trunk in selective positions from sitting to standing. The device is equipped with strain-gauge load cells to monitor flexion, extension, or rotation torques of the trunk. A similar, portable device was also developed for testing patients in a clinical setting. In addition, preliminary modifications of another device will permit the analysis of multiple channels of myoelectric signals and track the median frequency of the signal.

Results—Data from numerous chronic lower-back pain patients and normal controls have been collected and are being analyzed for several areas of investigation. First, we have documented the repeatability of the myoelectric signal parameters that comprise a fatigue pattern. In this same series of investigations, we have also established the sensitivity of these measures to the level of accuracy with which a surface electrode is relocated from one day to another or for different times in the same day. This information will be vital in establishing future protocols and interpreting our data.

Secondly, we have investigated the recovery process of median frequency measurements of lower back muscles following sustained fatiguing contractions. Recovery following rest periods of 1, 5, and 15 minutes were compared for control subjects. Similar tests are planned for lower-back pain patients.

Finally, we are targeting the first in a series of specific subcategories of lower-back patients to be tested by our assessment technique. We are testing patients with at least a 6 month history of chronic back pain without radiographic evidence of spinal abnormalities. This group is being tested according to the same protocols for previous tests on control subjects. Future tests are planned for other categories of lower-back pain.

This material was presented in November 1986 at the Eighth Annual Conference of the IEEE Engineering in Medicine and Biology Society in Fort Worth, Texas, and during the same month at the 16th Annual Meeting of the Society for Neuroscience in Washington, D.C.

Muscle Fatigue and Respiratory Failure

Bartolome R. Celli, M.D.; John Rassulo; Maria Bermudez, M.D.

The Pulmonary Center, Boston University School of Medicine, and the NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Boston University*

Purpose—Over the last year, the Pulmonary Center and the NeuroMuscular Research Center have developed a close liaison in an attempt to study the electrophysiologic phenomena that take place in the respiratory muscles. The studies were performed on volunteer subjects and patients with emphysema and chronic bronchitis. The studies are directed at evaluating the way in which respiratory muscles are coordinated and genesis of respiratory failure. Further understanding of these phenomena may lead to the development of strategies directed at improving the function of the muscles in those patients whose lung disease is such that there is little ventilatory reserve.

Progress—Data were obtained at University Hospital and Boston City Hospital on patients with lung disease and in normal subjects. Data analysis was

performed in a joint form at the physiology laboratory and at the NeuroMuscular Research Center. Myoelectric signals from different muscles, including the diaphragm and other accessory muscles of respiration, were obtained while the subjects and patients performed different activities, such as arm and leg exercises, resistive breathing, and voluntary hyperventilation, that stressed the respiratory muscles. The data were analyzed and correlated with the observed changes. Patients were then placed in either a rehabilitation program or a respiratory muscle resting plan, and the studies were repeated in 2 to 3 weeks to evaluate progress.

This joint research promises to enlarge our knowledge in the field of pulmonary physiology and introduces a new dimension in our capacity to plan better therapy.

Muscle Fatigue and Myoelectric Signal

Carlo J. De Luca, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Purpose—The use of the myoelectric signal to measure objectively the rate at which a muscle fatigues has numerous rewarding prospects. The approach is based on the proven fact that the frequency spectrum of the myoelectric signal detected with surface electrodes changes in a systematic fashion during sustained contractions. High-frequency components decrease in amplitude, while low-frequency components increase. Various studies during the past two decades have searched for the cause of this frequency shift and have attempted to determine whether the change originates from the physical properties of muscle fibers, such as their conduction velocity, or originates from control properties, such as firing statistics. Although the origin of the change is not clearly understood, the effect on the frequency spectrum is consistent and is related to the progression of a sustained muscle contraction. For this

reason, it provides a useful mechanism for assessing the involvement of the physiological component in the fatigue characteristics displayed by a task performed by individuals.

The objective measurement of physiological fatigue is essential to offset the seriously erroneous subjective evaluations that occur when psychological components are not isolated. Consequently, it is a vital tool in both industrial and healthcare environments, where the evaluation of fatigue-producing tasks is important.

Progress—To achieve these goals, we have developed a device called the Muscle Fatigue Monitor (MFM) which automatically, on-line and in real time, calculates and plots a single-parameter measure of the frequency shift.

Muscle Fatigue Monitor

L. Donald Gilmore, A.B.E.E., and Rudy Nyhuis

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: *Liberty Mutual Insurance Company*

Progress—The Muscle Fatigue Monitor (MFM) is an instrument that allows us to objectively measure muscle fatigue in subjects in both laboratory and field environments. The device has evolved through a series of stages, culminating in the present form which calculates the median frequency of the myoelectric signals that occur during a sustained contraction, using electrodes placed on the skin above the subject's muscle. Changes in the median frequency during a sustained muscle contraction are associated with the muscle fatigue process. A detailed description appears in our paper, "Muscle Fatigue Monitor (MFM): Second Generation," published in *IEEE Transactions on Biomedical Engineering*, January 1985. A portable device, the MFM has proven to be a powerful tool for studying the underlying processes of muscle fatigue.

In an effort to make the MFM concept available

to other researchers, we have developed a more generalized MFM instrument based on the popular IBM PC computer. This system offers the advantages of powerful color graphics, data manipulation, and commercial software well-suited to the laboratory environment. In April 1986, a prototype version of the IBM PC-based MFM system was demonstrated at the International Rehabilitation Exhibition in New York City.

The final hardware design of a dual-channel signal processing card is complete. It incorporates circuit modifications that enhance the dynamic performance of the device. These modifications allow measurement of the fatigue process in muscles performing cyclic activities such as walking or repetitive manual handling tasks in the workplace. The present device is now undergoing extensive evaluation coupled with the development of a modularized software package

necessary to complete the fatigue measurement system. Plans are underway to incorporate our IBM PC-based MFM into a portable trunk analysis system

to investigate the fatigue process in the muscles of the lower back.

Motor Unit Properties Investigated by Voluntary and Electrically Elicited Contractions

Marco Knaflitz, M.S., and Roberto Merletti, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215 and Politecnico di Torino, Torino, Italy

Sponsor: *Liberty Mutual Insurance Company*

Purpose—The clinical application of functional electrical stimulation techniques on muscles is limited by several factors and in particular by the high rate of fatigue observed during electrically elicited contractions. But the application of these techniques within a laboratory setting does provide a means of externally controlling the firing rate of motor units, thereby enabling researchers to conduct a quantitative study of the effect of the firing rate on the resulting myoelectric signal spectral properties and on muscle fatigue.

Progress—This study was begun in 1985 to develop optimized strategies for electrical stimulation. The results of these experiments showed that during voluntary contractions, motor units of the human tibialis anterior are recruited with ascending order of conduction velocity, reflecting an ascending order of fiber size. These results are consistent with other results found in the literature, and support the general notion of *size principle*. During stimulated contractions with surface electrodes, motor units

were recruited in a progression which was not necessarily related to the magnitude of their conduction velocity. Both during voluntary and electrically elicited contractions, mean and median frequencies were not found to be proportional to the mean muscle fiber conduction velocity.

The present experimental protocol focuses on obtaining more data about motor unit behavior and evaluating the repeatability of results obtained from certain subjects on different days. In this protocol, electrical stimulation of muscles is performed at different frequencies in order to evaluate the effect of firing rate on fatigue and spectral parameters.

Results—Preliminary results show that the behavior of a subject is reasonably repeatable on different days and confirms that median and mean frequencies are not always proportional to the mean muscle fiber conduction velocity. This work was presented (abstract) in November 1986 at the Eighth Annual Conference of the IEEE Engineering in Medicine and Biology Society, in Fort Worth, Texas.

D. Ligaments and Tendons

Structural and Functional Properties of Normal and Healing Ligaments

Savio L.-Y. Woo, Ph.D.

Orthopaedic Bioengineering Laboratory, Veterans Administration Medical Center, San Diego, CA 92161

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—The focus of the Orthopaedic Bioengineering Laboratory is the mechanics of soft tissues such as ligaments, tendons, and cartilage. Of primary interest are the structural and mechanical properties of normal and healing tissues and the development

of the specialized techniques necessary to study them.

Since the inception of this project, our laboratory has devoted significant effort in developing new and improved methodology which accurately character-

izes the quasi-static and nonlinear viscoelastic properties of parallel-fibered soft connective tissues, i.e., tendons and ligaments, and the correlative biochemical changes. Using the video dimensional analyzer system, we are able to study the biomechanical properties along the bone-ligament complex. As a result, we have evaluated the healing of the medial collateral ligament (MCL) in a rabbit model whereby the mechanical properties of the MCL substance (stress-strain curves) were evaluated together with the structural properties (load and energy absorbed at failure, mode of failure, etc.) of the MCL-bone complex. A plateau of improvement was found for these parameters which suggested that ruptured rabbit MCL without treatment is not capable of fully achieving normal ligament properties.

Preliminary Results—We have found that in rabbits, the total collagen mass of surgically transected MCL increased with healing time. Furthermore, Type I collagen was partially replaced by Type III as a result of increased scar formation. The same trend was noticed in the healing canine MCL. Biomechanical studies performed describe the effects of age, a variety of surgical techniques and treatment regimens, storage by freezing, and test environments. As a result, new techniques have been established that allow for a more accurate assessment of healing ligaments. For example, a new five-degrees-of-freedom knee laxity device is now available for analyzing the varus-valgus function of the knee, secondary to ligament repair. Using this device, it was discovered that under normal knee motion, the healing MCL was protected from valgus stresses by other joint structures, particularly the anterior cruciate ligament (ACL). This finding was further confirmed by an *in vivo* pilot study. In this study, the data showed that at the early healing periods, the properties of MCL with either full or

partial laceration of the ACL were not as complete as in the case of intact ACL. At six weeks, knee joints with a partially lacerated ACL were more lax (exp./control = 1.8 ± 0.2) than those with normal ACL (1.6 ± 0.5), but those with no ACL were extremely lax (2.7 ± 0.2). Additional biomechanical and biochemical tests plus longer-term experimental animals are ongoing to determine the effect of laxity on the healing MCL.

Future Plans/Implications—We plan to evaluate the ligament repair process in a model synovial joint system. Specifically, we plan to study the functional role of the healing MCL and how its injury would change the kinematics of the knee joint. A variety of treatment and activity conditions will be used in order to determine which set of conditions will maximize the ligament healing, function and strength.

Publications Resulting from This Research

- Treatment of Medial Collateral Ligament Injury: I. The Importance of Anterior Cruciate Ligament on the Varus-Valgus Knee Laxity.** Inoue M, McGurk-Burleson E, Hollis JM, Woo SL-Y, Award Paper. *American Journal of Sports Medicine* 15(1):15-21, 1987.
- Treatment of Medial Collateral Ligament Injury: II. Structure and Function of Canine Knees in Response to Differing Treatment Regimens.** Woo SL-Y, Inoue M, McGurk-Burleson E, Gomez MA, Award Paper. *American Journal of Sports Medicine* 15(1):22-29, 1987.
- Temperature-Dependent Behavior of Isolated Canine Medial Collateral Ligament.** Woo SL-Y, Lee TQ, Gomez MA, Sato S, Field FP, *Journal of Biomechanical Engineering* 109:68-71, 1987.
- Tensile Properties of the Medial Collateral Ligament as a Function of Age.** Woo SL-Y, Orlando CA, Gomez MA, Frank CB, Akeson WH, *Journal of Orthopaedic Research* 4:133-141, 1986.
- Effects of Postmortem Storage by Freezing on Ligament Tensile Behavior.** Woo SL-Y, Orlando CA, Camp JF, Akeson WH, *Journal of Biomechanics* 19:399-404, 1986.
- A New Methodology to Determine the Mechanical Properties of Ligaments at High Strain Rates.** Peterson RH, Woo SL-Y, *Journal of Biomechanical Engineering* 108(4):365-367, 1986.

Structural and Functional Properties of Normal and Healing Ligaments (Project Extension)

Savio L.-Y. Woo, Ph.D.

Veterans Administration Medical Center, San Diego, CA 92161

Sponsor: VA Rehabilitation Research and Development Service (Project #1A188-3RA)

Purpose—The objective of this research is to evaluate the ligament repair process in a model synovial joint system. Specifically, we plan to study the

functional role of the healing medial collateral ligament (MCL) and how its injury would change the kinematics of the knee joint. Two forms of MCL

tears (one by simple, sharp transection of its mid-substance, the other by Z lengthening plus the removal of 2 mm of ligament material) will be studied. A variety of treatment and activity conditions will be used in order to determine which set of conditions will maximize the ligament healing, function, and strength. Furthermore, how the functional role of the anterior cruciate ligament (ACL) affects MCL healing will be evaluated. To achieve these goals, it will be necessary to first determine the influence of surgical repair versus conservative treatment on the size and strength of the repair/healing ligaments. These experiments will be followed by a series of studies to evaluate the factors such as ACL deficiency, rigid immobilization, cage activity, normal activity, controlled passive motion, and rigorous daily exercise programs on the ligament repair process. The timing of the onset of these manipulations and their magnitude and frequency will have to be optimized in order to achieve the most rapid and complete remodeling of the repaired/healing ligaments.

We are also interested in studies involving the use of therapeutic agents to counteract contracture developed secondary to immobilization. Promising agents such as 17β -estradiol and hyaluronic acid will be tested, as these agents have been proven to be useful in minimizing the joint stiffness secondary

to rigid immobilization.

Evaluation of the quality of ligament healing and repair will include correlative studies using morphologic, histologic, bioengineering, and biochemical techniques. With the new biomechanical testing procedures developed in our laboratory, it will be possible to study the laxity of the knee, the properties at the repair line, and the remainder of the bone-ligament complex independently. This is of great importance because the effect of treatment on the elements along the ligament-bone complex, vis-a-vis area of repair, area of ligament proximal, and viscoelastic characteristics of the repair ligaments will also be analyzed and compared to normal ligaments. In addition, the study of joint laxity using our newly developed tools will aid in the evaluation of the ligament function during physiological knee movements. Histological studies and biochemical quantification of water content, total hexosamine as representation of glycosaminoglycans, cellularity (DNA), total collagen, types of collagen, and the reducible crosslinks of collagen of the repair and normal sites will also be done. As a result of this interdisciplinary study, correlation between histological, biochemical, and biomechanical changes of normal and repaired ligaments (various injury models, treatments, and activity levels) will be possible.

XII. Neurological/Vascular Disorders

A. General

Electrophysiological Studies on Nerve Repair and Regeneration

Vincent R. Hentz, M.D.; ShaoJun Xiao, M.S.; Kevin C. McGill, Ph.D.

Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Although modern microsurgical technique makes nerve repair possible, it rarely results in desired nerve functional recovery. In the treatment of nerve injuries, physicians mainly depend on subjective criteria to make clinical decisions regarding the repair method and the type of care in the regeneration process. A quantitative characterization of nerve lesion, repair, and regeneration would offer to physicians an objective tool to measure the degree of lesion, to test the methods available, and to develop better clinical methods.

With the help of an evaluation tool, better methods of nerve repair could be developed such as optimum control of the size and configuration of the scar at the repair site. Better nerve regeneration aids could be developed such as a plastic nerve coupler, external electromagnetic fields, etc. Our goal is to equip physicians with a tool to quantitatively assess an abnormal nerve so that the appropriate clinical treatment can follow.

Progress—A traditional evaluation method is to measure the area ratio of two compound action potentials (CAPs) recorded from stimulating axons both distal and proximal to the repair site. This indicates the fraction of axons functionally connected. Such a method does not give the subpopulation contribution, and requires monophasic recordings that must be obtained intraoperatively. We developed the distribution of added delays (DAD) as a quantitative description of the focal lesion or repair site that can provide detailed information regarding the relative number and health for each fiber group; and we propose two methods for evaluating the DAD, namely, intraoperative and skin surface evaluation methods.

A CAP is conventionally regarded as a linear superposition of Single Fiber Action Potentials (SFAPs). In dealing with the intraoperative evaluation, the area of SFAPs is assumed to be a universal constant that can be estimated from available experimental data. By invoking statistical arguments, the first approximation for the distribution of added delays due to a mechanical lesion is proposed to be the same for all conduction-velocity groups. The DAD is then computed from the recorded CAPs using the intraoperative monophasic SFAP-CAP model. The parameters in the model will also be applied to the skin surface evaluation method. In the latter approach, the peripheral nerve is idealized as existing in a semi-infinite volume conductor. The method of images is used to find the SFAPs on the skin surface. Since there is more uncertainty in the skin surface evaluation method than the intraoperative evaluation method, comparison of results obtained from the two methods will enable optimization of the parameters of the volume conductor model.

Preliminary Results—The animals and equipment are already on-line for data acquisition. For the intraoperative evaluation method: the DCV and DAD have been calculated from previously recorded data from monkeys. Mathematically, the reconstruction technique shows that the numerical results are consistent with the model. Physically, the results agree with expectations. Currently, we are designing an experimental verification of the DAD results.

For the skin surface evaluation method the physical and mathematical analysis is on hand. The numerical computation programs for calculating the DCV and DAD are under development.

Nerve Coupler: Sutureless Peripheral Nerve Repair at the Fascicular Level

Joseph M. Rosen, M.D., and Deirdre Marshall, M.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Our purpose is to improve the functional results of current methods of peripheral nerve repair. Suture results are often unsatisfactory because of poor coaptation of fascicles, scar tissue at the repair site and neuroma formation. This study continues the development of a new method of sutureless, mono-fascicular, peripheral nerve repair.

Progress—The coupler consists of three parts: proximal and distal cuffs and a central coupler. The ends of a transected nerve (fascicle) are pulled snugly into the proximal and distal cuffs with the aid of a fine hook. The cuffs are then fitted tightly into the central coupler. Twenty-five rats were used to compare the nerve coupler to standard suture repair. The animals were evaluated after 1, 2, and 3 months for the short-term study and from 9–15 months for the long-term study. The short-term animals were evaluated by qualitative histology. The long-term animals were evaluated by qualitative histology, and, in addition, quantitative histology and physiology to determine axonal regeneration.

Preliminary Results—Short-term animals showed fewer adhesions in the coupler repairs than in the suture repairs. Neuromas were absent in all coupler repairs and minimally present in the suture repairs. Alignment was slightly better in the coupler repairs than in the suture repairs. In the long-term animals, there were increased adhesions in the suture repairs, compared to the coupler repairs. Repair site organization appeared slightly better in the coupler repairs than in the suture repairs. The quantitative histology showed the suture repairs to have slightly greater mean diameters than the coupler repairs. The electrophysiological evaluation showed coupler repairs to be better than the suture repairs in six of the ten animals, but this was not statistically significant.

Future Plans/Implications—Further refinements of the nerve coupler are being planned. The coupler is also being used to introduce adjuncts to improve nerve regeneration.

Factors Limiting the Tactile Perception of Form

Jack M. Loomis

Department of Psychology, University of California, Santa Barbara, CA 93106

Sponsor: National Institutes of Health

Purpose—The proposed work will continue a program of empirical and theoretical research that seeks to understand the sensory and non-sensory factors that limit the perception of tactile spatiotemporal patterns. The earlier research has led to a model of recognition of static raised characters sensed by the finger. The major thrust of the work will be to further test the model and hopefully extend it to a broader empirical domain (to spatiotemporal patterns presented to different body sites using a variety of

tactile displays). Among the experiments being proposed are: 1) further work on the measurement of cutaneous spatial sensitivity using sinewave gratings; 2) a comparison of pattern perception at different body loci; 3) an attempt to disentangle sensory and nonsensory factors that account for the large individual differences in tactile pattern perception; and, 4) tactile (and visual) recognition of characters drawn from various set sizes (e.g., 8, 15, and 26 characters).

Neural Pathways Involved in Tactile Discrimination

Benjamin H. Pubols, Jr.

Good Samaritan Hospital and Medical Center, Portland, OR 97209

Sponsor: *National Institutes of Health*

Purpose—The proposed research is part of a project whose long-term goal is to add to our understanding of the tactile information processing capabilities and limitations of the somatosensory system, especially those neural regions and systems responsible for processing tactile information derived from mechanical stimulation of the glabrous surfaces of the hand. Specifically, it is proposed to examine functional properties and stimulus-response relationships of single neurons of three spinal pathways which project, directly or indirectly, to the thalamic ventrobasal complex: the spinocervical tract, the postsynaptic dorsal column system, and the spinothalamic tract.

Microelectrodes will be used to record extracellular activity of cell bodies or fibers in response to controlled mechanical stimulation of the glabrous skin of the raccoon's forepaw. Neurons will be identified as belonging to one of these three systems by antidromic electrical stimulation of the appropriate region of spinal cord or brain stem. Specific parameters to be examined include modality and adaptive properties, absolute thresholds, and receptive field areas, as well as effects of controlled

mechanical stimulus velocity, displacement, and force on both dynamic and static discharge. Additionally, neurons will be sought which display properties suggesting excitatory or inhibitory convergences, and which display properties of feature detectors (e.g., preferential response to edges or laterally moving stimuli). Properties of neurons of the three spinal pathways will be compared with each other, as well as with properties of both primary afferents and neurons of the cuneate nucleus and thalamic ventrobasal complex, previously studied in this laboratory.

These studies should contribute to our knowledge of the differential contribution of three major somatosensory pathways to the processing of tactile information acquired by a behaviorally salient tactile organ system, the forepaw or hand, especially its glabrous surfaces. This, in turn, should provide information relevant to the design of devices for the utilization of tactile information by individuals handicapped in other sensory modalities. Findings should also have neurological relevance to the differential diagnosis of spinal cord injury or disease.

A New Approach in the Relief of Pain of Leprous Neuritis

J.M. Mehta, M.B.B.S., and V.N. Kulkarni, B.Sc.(PT)PGDR.

Dr. Bandorawalla Leprosy Hospital, Kondhawa, Pune 411022, India

Sponsor: *Poona District Leprosy Committee*

Purpose—Leprosy neuritis is known for its associated excruciating pain. A search of the literature, however, did not reveal a reference to the use of transcutaneous nerve stimulation (TNS) for relief of the pain of leprosy neuritis. It is the use of electrical stimulation for the relief of pain in leprosy that led to the present investigation with the following goals: 1) to demonstrate the effectiveness of TNS; and 2) to develop a suitable method of application.

Progress—The instrument of stimulation used in this study was a compact device working on dry cells which could be operated by the patient. Out of 40

patients studied, 33 had ulnar nerve involvement, 5 had median nerve involvement, and 2 had lateral popliteal nerve involvement. All the patients had severe pain and no sustained relief was obtained by pain-killing drugs or splints. Subjective parameter used to measure the pain were: a) 4+ severe intolerable pain making patients extremely restless with much hyperaesthesia and no relief with long-term drugs and splints; b) 3+ pain less than 4+ with less hyperaesthesia; c) 2+ pain only on light touch and movement of the limbs; and, d) 1+ pain only on tapping the nerve.

Electrodes were placed above and below the site

of pain. For ulnar nerve therapy, they were placed above and below the medial epicondyle. For the median at wrist, both electrodes were placed on the flexor surface of the forearm. For the lateral popliteal nerve at the neck of the fibula, both electrodes were placed on the anterior surface of the leg. By turning the output and rate control knobs, the maximum tolerable sensation to the patient was adjusted. A minimum of one-half hour duration for each test was set. Additional tests were given, depending on the severity of pain.

Results—There was a total relief of pain in 29 patients; 8 patients showed partial relief; and 3 patients had no relief at all. TNS works on the following hypothesis: when nociceptive impulses reach the posterior horn of the spinal cord a “gating”

or control mechanism determines which signals ascend the spinothalamic tract to the brain, where pain is perceived. The “gate” is facilitated or inhibited by peripheral afferents. Increased C fiber action inhibits the gate, allowing passage of impulses, while a relative increase in large myelinated A fiber activity closes the gate, blocking pain.

The results indicate a positive role of TNS in the treatment of leprosy neuritis, as most patients obtained a remarkable degree of relief from pain. It is not possible to predict beforehand whether a particular patient will be benefitted by TNS. But, as TNS is such a simple procedure, the authors feel that it should be tried in all cases of nerve pain. In cases where deformity is threatening, other measures like steroids, etc., should be implemented immediately, without waiting to observe the results of TNS.

Treatment of Leprous Neuritis by Perineurial Steroid Injection

S.B. Sane, M.S.; V.N. Kulkarni, B.Sc.(PT)PGDR; J.M. Mehta, M.B.B.S.
Dr. Bandorawalla Leprosy Hospital, Kondhawa, Pune 411022, India

Sponsor: Poona District Leprosy Committee

Purpose—Leprosy is the single cause of peripheral neuritis in the world today and, if left untreated, can lead to muscular paralysis and consequent deformities such as claw hand, foot drop, lagophthalmos, etc. Early treatment of leprosy neuritis can totally prevent the occurrence of deformities. Leprous neuritis is also known for associated excruciating pain. Hence, the treatment aims at relief of pain and prevention of muscular paralysis.

The nerve damage in leprosy occurs for two reasons: 1) raised intraneural pressure due to inflammation with resultant ischaemia; and, 2) when the nerve is thickened due to the intraneural changes, extraneural compression and sometimes traction trauma occur at specific sites of nerve involvement, adding to the severity. Depending on the severity of neuritis and nerve damage, it can be treated medically and/or surgically with the aid of physiotherapy. Medical treatment usually involves the use of oral steroids. The role of steroids as an anti-inflammatory agent that diminishes the nerve edema and controls the accentuated response of cell mediated immunity is well known. However, oral steroids for prolonged periods produce side effects such as water retention, G.I.T., etc. This led us to

the concept of perineurial steroid injections, which produce a safer and local effect.

Progress—The procedure consists of injecting a steroid depot preparation along the nerve, either diluted with distilled water and with or without plain Xylocaine (for instant pain relief). The study involved use of triamcinolone acetomide 10 mg. or 40 mg/ml. The study was conducted on 50 cases and included 27 ulnar nerves, 12 median nerves, and 11 lateral popliteal nerves. The injection was given for two purposes: 1) relief of pain; and, 2) as an aid to motor recovery by physiotherapy.

Use of distilled water as a diluent which is hypotonic to body tissues may help to extract the edema fluid from the nerve into the paraneural tissues. The relief of pain by steroid injection takes 1 to 2 hours. The patient gets instant pain relief by injection of 2cc plain 2 percent Xylocaine. Physiotherapy should be started immediately, if the injection is given with an aim at the motor recovery.

Results—Of 50 nerves injected, 26 were treated for relief of pain and 24 of these responded positively. In 24 cases where injection was aimed at motor

recovery, 20 responded favorably. It was observed that nerves treated for relief of pain included predominantly ulnar nerves and, on the whole, motor recovery in ulnar nerves was poor. However, the median and lateral popliteal nerves showed good motor recovery. Factors such as disease and passage through the rigid fibro-osseous tunnel, which increases the extraneural compression and traction trauma, attribute to the poor recovery of the ulnar

nerve.

It was observed that the majority of patients in the tuberculoid spectrum of the disease showed a good response and those with borderline lepromatous showed a poor or a temporary response. During therapy a close watch was kept on nerve function deterioration and, if so observed, prompt surgical intervention was sought.

Inhibitive Casting as an Adjunct to Therapy in Children with Cerebral Palsy

S. Jarvis, B.Sc., P.T.; S. Naumann, Ph.D., P.Eng.; C. Mosely; R. Tervo, M.D., F.R.C.P., F.A.A.P.
Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: *Research Department Seed Fund, Hugh MacMillan Medical Centre*

Purpose—The objective of this study is to examine the benefits of inhibitive casting as an adjunct to therapy for young children with cerebral palsy.

The specific goals of the project are as follows: 1) to determine the effects of inhibitive casts on gross motor function and range of motion in the lower extremity; and, 2) to determine the effects of inhibitive casts on the alignment of joints in standing, on the width of the base of support in standing and walking, and on the pressure points under the feet in standing.

Progress—This project is being carried out jointly between the Therapy Departments at the Hugh MacMillan Medical Centre and Bloorview Children's Hospital, and the Gait Laboratory in the Rehabilitation Engineering Department at the Hugh MacMillan Medical Centre.

Four children are participating in this study, two in a casted group, and two in a control group. Clinical and gait laboratory assessments are performed at 0, 4, 8 and 12 months. The children in the casted group were assessed both with and

without casts at 4 and 8 months, that is, at the beginning and end of the casting period. All four children are undergoing neurodevelopmental therapy throughout the study.

Clinical assessments include Gross Motor Function Assessment, assessment of reflexes and range-of-motion in the lower extremity joints. Gait laboratory assessments include measurement of alignment of joints, width of base of support during walking, stride length, and speed of walking.

Preliminary Results—To date, all four children have undergone three assessments, at 0, 4 and 8 months. Preliminary results indicate positive trends while wearing the casts, including a decrease in forward tilt of the pelvis, a decreased hyper-extension of the knee, increased dorsiflexion, and decreased valgus at the ankle in standing. The same changes are noted when the casts are not being worn, but to a lesser degree. Results from the final gait assessment will be used to determine the carry-over effect of wearing the casts.

B. Arthritis

Evaluation of Osteoporosis by Ultrasound and CAT-Scan

Subrata Saha, Ph.D.; J.A. Albright, M.D.; V.L. Giyanani, M.D.; H.E. Thompson, M.D.
Louisiana State University School of Medicine, Shreveport, LA 71130

Sponsor: Louisiana State University School of Medicine

Purpose—The diagnosis of advanced osteoporosis may be based on changes in the bone density and/or by measuring cortical bone thickness, both of which are generally determined from roentgenological examination of bone. However, the roentgenological evaluation of osteoporosis is qualitative in nature and it requires a minimum bone loss of 30 percent before an unequivocal roentgenological diagnosis of osteoporosis can be made. The aim of this study was to determine if cortical bone thickness and bone density can be measured accurately by ultrasound and CT.

Progress—Three embalmed human femurs were used in this study. The cortical bone thicknesses and bone densities were measured at 16 locations of each femur using a CT unit (Ohio - 2020, Technicare). Thicknesses at the same locations were then measured by ultrasound using the pulse-echo technique. An immersion-type transducer (Dapco, S1H5) was used at a frequency of 5 MHz with a pulse-repetition frequency of 100 Hz. Both the specimen and the transducer were immersed in a water tank. Once these ultrasonic measurements were completed, the bones were sectioned and the actual thicknesses at the same locations were measured with a micrometer. The bone densities at each location were also determined.

Preliminary Results—The individual micrometer measurements made on 48 locations were compared with the corresponding ultrasound and CT data. The correlation coefficients between the actual thickness with the ultrasonically measured thickness was 0.95 and with the CT 0.62. We attribute the error in the CT data partly to the technique involved in the measurement (it can read only integral numbers) as

well as to the subjective nature in selecting bone edges and thus in positioning the electronic cursors. Variations between the actual bone densities for these samples were minimal and it did not show significant correlations with the attenuation of ultrasound.

The results of the *in vitro* study suggest that ultrasonic measurement of cortical thickness is more accurate than similar measurement by CT. Moreover, ultrasound does not use ionizing radiation, and it is significantly cheaper to use than the CT. Thus, ultrasound technique, when fully developed, may be more suitable for large scale screening for osteoporosis.

Future Plans/Implications—This study is being continued in order to compare the relative accuracy of ultrasound, CT, and photon absorptiometry methods in evaluating osteoporosis.

Publications Resulting from This Research

Ultrasonic and CT Measurement of Skeletal Mass. Saha S, Singh S, Giyanani VL, Thompson HE, Albright JA, *IEEE 1984 Frontiers of Engineering and Computing in Health Care*. Proceedings of the 6th Annual Conference IEEE Engineering in Medicine and Biology Society, 112-114, 1984. (Phys. Abstr. 68007, 1, July 1985).

Osteoporosis. Davies R, Saha S, *American Family Physician*, 32(5):107-114, 1985.

Evaluation of Osteoporosis by Ultrasound and CAT-Scan. Saha S, Singh S, Albright JA, Giyanani VL, Thompson HE, WFUMB '85, Suppl. No. 1, *Journal of Ultrasound in Medicine and Biology*, 453, 1985.

Wave Propagation Characteristics in Long Bone Reflecting Structural Changes Due to Aging. Chen IH, Saha S, *Biomedical Engineering V: Recent Developments* (S. Saha, Ed.), Pergamon Press, 388-391 (abstract in *Biomaterials, Medical Devices and Artificial Organs*, 14(1 & 2):121, 1986).

Wave Propagation Characteristics in Long Bones to Diagnose Osteoporosis. Chen IH, Saha S, *Journal of Biomechanics*, 20(5): 523-527, 1987.

Arthritis Rehabilitation Unit

Carolyn Brunner, M.D.; Cynthia Stabenow Kulp, OTR; Stephen Wegener, Ph.D.; Amy O'Leary, MA
Rehabilitation Research and Training Center, University of Virginia, Charlottesville, VA 22908

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The purpose of the Arthritis Rehabilitation Unit (ARU), which consists of five beds in a 22-bed general rehabilitation unit, is to identify methods of managing arthritis patients and define protocols for rehabilitation professionals working with this patient population. The staff consists of a rheumatologist, orthopaedic surgeon, psychiatrist, rehabilitation nurses, occupational and physical therapists, social worker, psychologist, a vocational rehabilitation counselor and therapeutic recreation counselor.

Progress—To date, more than 180 patients have been admitted to the inpatient rehabilitation program. The primary diagnosis is rheumatoid arthritis, although patients with other diagnoses such as osteoarthritis and ankylosing spondylitis are admitted.

During the grant period (1983-1987), the staff of the ARU has been collecting demographic data on patients participating in the program. In addition, the staff is using the Arthritis Impact Measurement Scale, an outcome measure developed at the Boston University Multipurpose Arthritis Center, to assess patients on nine scales: mobility, physical activity, dexterity, household activity, social activity, activities of daily living (ADL), pain, depression, and anxiety. Three-month, 6-month, 12-month, and 18-month follow-up data are collected on all the patients at the rehabilitation unit to help determine the long-term benefits of the rehabilitation program. In addition, psychological testing has been completed, on admission, for more than half of the patients with rheumatoid arthritis.

Training efforts have included a program in arthritis for the rehabilitation nurses on the unit, a physical therapy consultant to discuss management of musculoskeletal problems in arthritis for the entire staff, a statewide program for public health nurses in the rehabilitation of patients with arthritis, and a nationwide video conference on management of arthritis using the multidisciplinary team approach.

Results—The staff has completed a survey of more than 500 rehabilitation units to help determine the scope of arthritis rehabilitation in the United States and the need for staff training in management of arthritis patients.

The ARU staff has been engaged in a cooperative effort with the Virginia Department of Rehabilitation Services (DRS) to examine the nature and extent of services for clients with arthritis. DRS data on arthritis clients in 1985 has been reviewed. A sample of 52 arthritis clients referred to DRS in 1986-87 participated in a project to maintain their employment. Project strategies included job site visits and job site modifications using rehabilitation engineering and the resources of DRS.

The staff has completed two research projects. One project was an investigation of sleep problems in patients with rheumatoid arthritis. A second project was an outcome study of equipment use following discharge of 50 patients from the inpatient rehabilitation program. A third study—validation of a self-report activity analysis instrument—is an ongoing project.

Impact of Arthritis Self-Care for Rural Persons

Jean Goeppinger, Ph.D., R.N.

University of Virginia Medical Center, School of Nursing, Charlottesville, VA 22903

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The purpose of the Arthritis Self-Care (ASC) Project is to develop and evaluate the impact of arthritis self-care programs for rural persons. The

independent variable is a type of self-care program, home study/correspondence course or small group; the dependent variables are knowledge, self-care

behavior, helplessness, pain, depression, disability, and social support. The extent of participation in the self-care program, assessed by the number of lessons completed and extent to which behavioral contracts are made and fulfilled, is controlled for statistical purposes.

Progress—We completed the curriculum, developed instructional packages for both the home study and small group programs, and began community entry in 1983 and 1984. In 1985 and 1986 we completed training programs for the 55 community members who implemented the self-care programs in the counties designated as the research setting and offered the intervention, collected data, and began data analysis. Throughout the 5 years we have presented the work of the Project at professional meetings: we have begun to publish our findings.

Preliminary Results—Our self-care programs reached about 500 rural Virginians. Most of the participants

were older, white females with diagnoses of osteoarthritis (85 percent) and rheumatoid arthritis (15 percent). Most (95 percent) completed at least five of the six lessons comprising the programs.

Although all follow-up data have been collected, we have not completed data entry and analysis. Initial analyses suggest that our self-care programs have: 1) increased participants' knowledge and practice of self-care behaviors and decreased their feelings of helplessness to manage their diseases; and, 2) had no effect on participants' pain, disability, and depression. Finally, the home study and small group programs appear to have similar impacts. Further analyses, to clarify the meaning of these initial findings, are in progress.

Future Plans—More ambitious projects to explain the processes by which self-care education has an impact on key clinical parameters and to identify the types of persons most likely to benefit from self-care education are planned.

Endurance Training with Management of Fatigue in Rheumatic Arthritis and Systemic Lupus Erythematosus

Matthew H. Liang, M.D.; Celeste Robb-Nicholson; Thomas Graboys
Brigham and Women's Hospital, Boston, MA 02115

Sponsor: *National Institute on Disability and Rehabilitation Research; Department of Education*

Purpose—The goals and objectives of this study are threefold: 1) to evaluate the long-term costs and effectiveness of aerobic training in improving fatigue, work capacity, and quality of life in rheumatoid arthritis (RA) and systemic lupus erythematosus (SLE); 2) to use aerobic conditioning in SLE and RA as a probe and define the physiologic and metabolic parameters of fatigue and their changes after conditioning; and, 3) to define work ability and performance in patients with SLE and RA.

Progress—This project has been funded since October 21, 1986. As of July 1, 1987, 73 of the 400 potential subjects have been sent recruitment letters.

Of this number, 22 subjects have agreed to participate over the phone, 11 declined participation, 5 have been excluded, 11 cannot be reached, and 24 are presently being telephoned. The first participant will finish the 12-week aerobic training in the middle of August. One subject is being entered into the study each week.

Future Plans/Implications—Fatigue is a disabling symptom in many chronic diseases and causes considerable loss of productivity and impaired quality of life. Aerobic exercise, if effective, could provide an economic rehabilitation intervention.

Multipurpose Arthritis Center: Community Component—Coping Responses to Rheumatoid Arthritis

Glenn G. Affleck

University of Connecticut Health Center, Farmington, CT 06032

Sponsor: *National Institutes of Health*

Progress—The NIH Multipurpose Arthritis Center is currently funding four major educational efforts. The computer assisted patient education project has successfully completed a program for patients and families of patients with rheumatoid arthritis. This has been well received by patients and is currently undergoing testing by both patients and their families. Editing of the program will proceed along with the evaluation process. The physician assisted program has completed a longitudinal study in which physicians are in contact with a patient with rheumatoid arthritis (the computer) over a period of seven years. This is being evaluated by various types of physicians and by medical students and editing of the program will continue as the evaluation proceeds. The third program involves developing

methods for teaching Family Medicine Residents and is continuing during the next year in which more data will be available and the testing methodology improved. The fourth program involves teaching methodology and content development in the area of physical therapy. Undergraduate teaching of rheumatology by our NIH Multipurpose Center funded physical therapist-educator is now in progress and efficacy will be evaluated during the coming year.

Results—The research project on C3 phenotypes has led to interesting findings in that juvenile onset systemic lupus erythematosus patients have a higher incidence of one phenotype than adult onset patients. Patients with other rheumatic diseases are currently being evaluated.

General Clinical Research Center: “Riadura” and NSAID in Rheumatoid Arthritis Treatment

Robert M. Bennett

Health Sciences Center, Oregon University, Portland, OR 97201

Sponsor: *National Institutes of Health*

Progress—The Clinical Research Center at the University of Oregon Health Sciences Center provides inpatient, outpatient, and Core laboratory facilities for use by faculty investigators conducting a series of studies on the etiology, pathophysiology, and treatment of a variety of human diseases. The Center serves as a unique institutional resource for bringing together scientists from a variety of preclinical and

clinical disciplines for multidepartmental cooperative investigative efforts. Important programs of research currently underway in the Clinical Research Center include oncology, vasospastic and atherosclerotic vascular disease, immunology, endocrinology, narcotic addiction, cardiology, nephrology, and hypertension.

Multipurpose Arthritis Center: Professional Education in Sexual Rehabilitation of Arthritis Patients

Daniel J. Blake

University of Alabama, School of Medicine, Birmingham, AL 35294

Sponsor: *National Institutes of Health*

Progress—The Multipurpose Arthritis Center (MAC) of the University of Alabama in Birmingham (UAB)

is a multidisciplinary effort by faculty and staff of the Schools of Medicine, Dentistry, Nursing, Public

Health, and Community and Allied Health, and the University Hospitals and Clinics. A broad spectrum of ongoing and proposed activities is focused on basic and clinical research, education, community activities, and health services research.

Research in MAC includes studies in the areas of immunology, virology, mycoplasmaology, molecular biology, genetics, connective tissue biochemistry, and clinical rheumatology. The Education Component spans the spectrum of professional, allied health, postgraduate and public and patient educational activities. The Community and Health Services Research Component highlights socioeconomic factors that influence the well-being of patients with rheumatic disease.

This application includes feasibility proposals in fundamental research from seven investigators to study basic mechanisms involved in the pathogen-

esis of the rheumatic diseases. Five new projects are proposed in patient and professional education. Six projects are proposed in the Community and Health Services Research Component, and include critical evaluation analyses applicable to this important area. In addition, three Core Units are proposed: continuation of the Hybridoma Core Facility, and development of a new Immunogenetics Core and a new Evaluation, Biostatistics, and Data Management Core Unit.

The overall goals are to coordinate existing arthritis programs and initiate new programs in arthritis so that we can achieve: 1) greater knowledge of the etiologies, pathogeneses and therapies of the rheumatic diseases; 2) better systems of health education; 3) documentation of current and improvement of future patient services; and, 4) a more enlightened community attitude toward arthritis.

Multipurpose Arthritis Center: Education Component—Arthritis Patient Education Model

Brenda Devellis

University of North Carolina, Chapel Hill, NC 27514

Sponsor: National Institutes of Health

Progress—The UNC-CH Multipurpose Arthritis Center (MAC) represents a broadly-based, coordinated effort by faculty and staff in the Schools of Medicine, Nursing, and Public Health toward development of new basic knowledge, enhanced education, and improved mechanisms for health care delivery in arthritis. Providing special impetus and support in this regard are the following: Area Health Education Centers Program; N.C. Rehabilitation Network; UNC Rehabilitation Program; the ongoing Arthritis Rehabilitation in Industry Program; and the N.C. State Arthritis Act and its legislated planning committee. Certain new directions in an already well-established immunology research program will be pursued, e.g., study of the idiotype/anti-idiotype network in human autoimmune disease, analysis of tissue deposited immune complex function in SLE, and the establishment of an Immunoreagent/Immunoassay Core Facility.

The major thrust of MAC proposed activities, however, concerns a series of innovative projects

in the Education and Community Components. These include: 1) study of a new psychosocial model for patient education; 2) development of educational models in arthritis for occupational and physical therapists, both as part of a core undergraduate curriculum, and also in the community for those already in practice; 3) development of a health care model for ambulatory elderly patients with arthritis to be conducted jointly by nurse practitioners and occupational therapists; 4) analysis of the Social Security Administration disability determination process for arthritis; 5) development of a model training program in arthritis and rehabilitation for industrial managers with applicability to the general problem of the worker with arthritis; and, 6) an epidemiologic study of patterns of arthritis care in Eastern North Carolina. In all of these projects, particular emphasis has been placed upon effective evaluation, which will be aided by an Evaluation Core.

A National Arthritis Data Source (ARAMIS)

James F. Fries

Stanford University, Palo Alto, CA 94304

Sponsor: *National Institutes of Health*

Purpose—The American Rheumatism Association Medical Information System (ARAMIS) is a rheumatic disease computer data bank system containing longitudinal clinical data for approximately 19,000 patients and 120,000 patient encounters, and representing more than 100,000 patient-years of observation. The system operates from an IBM 370/3081 computer at Stanford University and is accessed nationally through TYMNET or TELENET communications networks using the Time-Oriented Data Bank (TOD) data management system.

The program is based upon the premises that chronic diseases have become the most prevalent health problems, that study of such diseases requires observation of occurrences over prolonged time periods, that the expense of longitudinal study requires use of economies of scale, that patient outcome in chronic disease results from a complex interplay between multiple factors, and that many important questions need to be studied with observational, in addition to experimental, techniques. This program has the goal of improving knowledge, management, and patient outcome in arthritis by providing long-term information relating to disease severity, patient characteristics, social factors, and treatment to patient outcome. The program has two

major aims: first to continue to develop a national data resource of high quality, longitudinal, accessible clinical data, and second, to employ these data in a systematic, multicenter investigative program of major clinical questions in the rheumatic diseases.

Progress—Program priorities include the classification and definition of diseases, the systematic study of long-term (6 to 20 years) outcomes, the economic impact of illness and treatment, and study of regional and national differences. Thirty clinical investigators and epidemiologists at 12 institutions undertake over 50 projects annually. The present proposal includes classification studies of osteoarthritis, rheumatoid arthritis, vasculitis, and systemic lupus erythematosus, economic impact studies in each major disease, comparative studies of arthritis at different sites, population-based studies of incidence and prevalence, and long-term studies of outcome in rheumatoid arthritis, juvenile arthritis, scleroderma, systemic lupus, osteoarthritis, and following joint surgery. With this project, 15 years of data development at numerous institutions are brought to bear upon major clinical questions, and very large and detailed longitudinal patient data sets are made nationally available.

Multipurpose Arthritis Center: Stanford, CA

Halsted R. Holman

Stanford University, Palo Alto, CA 94303

Sponsor: *National Institutes of Health*

Purpose—The Stanford Arthritis Center (SAC) conducts research, educational, and patient care programs to improve health outcomes of arthritic patients. In particular, SAC designs and implements new educational and community programs and gauges their success by outcomes experienced by patients. To do so, SAC draws upon multi-faceted research activities, large numbers of patients and community physicians, cooperating hospitals and health services, a major system for managing data (ARAMIS),

and skills of economists, epidemiologists, educators, and health professionals in assessing new programs.

Central to SAC activities is development of reliable methods to evaluate health outcomes. SAC has developed instruments measuring functional status, symptoms, adverse effects of drugs and costs of health care for arthritic persons; other instruments, particularly concerning psychological variables and quality of life, are in developmental phases. This work depends upon a Core Unit which assists in

experimental design, instrument development, data management and computational issues, biostatistics and data analysis.

Progress—Seven successful programs will continue concerning: long-term outcomes for rheumatoid arthritis, juvenile arthritis and joint replacement; self-management education for patients; comparison of osteoarthritis outcomes in 3 different health services; comparison of team versus individual physician care of chronic arthritis of the elderly; and, treatment of refractory lupus nephritis with total lymphoid irradiation. Six new projects are added, all related

to chronic arthritis: identification of influential psychological factors; analysis of incidence by population characteristics; a new method for estimating indirect costs; the impact of exercise on incidence of osteoarthritis; distinction between seronegative and seropositive arthropathies; and, search for a pathogenic antigen in cartilage of rheumatoid joints.

Improved outcomes for arthritic patients nationally must occur within limits of financial resources. This Center develops and/or evaluates care programs for large groups of arthritic patients with the objective of improving the effectiveness, efficiency and satisfaction achieved by health services.

Northeast Ohio Arthritis Center Support: Legal Aspects of Chronic Illness: A Study of Arthritis Patients

Judith P. Lipton

Case Western Reserve University, Cleveland, OH 44106

Sponsor: National Institutes of Health

Purpose—The long-term objectives of this proposal are: 1) to expand efforts directed towards the education of health professionals, patients, families, and the general public; 2) to develop, implement, and evaluate prototype community/health services programs at a high level of scientific endeavor; and, 3) to expand clinical and basic research efforts. New programs in education include 1) an evaluation of use of the education-influential in teaching rheumatology to family practice training units; 2) studies of continuing graduate medical education in arthritis with emphasis upon involvement of the learner in the identification of objectives; and, 3) augmentation of an audiovisual library as an umbrella educational resource. Specific new community programs include 1) a systems analysis of arthritis health care delivery in Northeast Ohio; 2) identification of the legal needs of arthritis (chronically ill) patients; 3) studies of the perceived needs of arthritis patients, and available

resources to meet those needs as viewed by the patient and community health nurses; 4) the establishment of an industrial database pertaining to arthritis problems and management in Northeast Ohio; and, 5) an evaluation of NEOMAC/community organizational behavioral interrelationships.

Research programs are targeted to study cartilage metabolism and osteoarthritis, mediators of inflammation, acute phase reactants, the immune response in arthritis, genetic/clinical interplays in ankylosing spondylitis, and myopathic disorders. Core programs include a cell/tissue culture unit, and an evaluation/education core as an overall resource to the center's project components. Administration includes administrative policy, executive, steering (operations), and community advisory committees to fully interdigitate center/University/community interface.

Multipurpose Arthritis Center: Community Component—Arthritis Impact Measurement Scales

Robert F. Meenan

Boston University School of Medicine, Boston, MA 02118

Sponsor: National Institutes of Health

Purpose—This proposal describes in detail a plan to expand and strengthen the Boston University Multipurpose Arthritis Center. A program of activities and specific projects will be pursued in three major components: research, education, and community/health services research. The proposal also describes a plan to support areas of special research interest by means of two core units, and to continue an effective administration component.

The research component will build on a strong base of work funded from other sources. In addition, four developmental and feasibility studies are proposed: 1) a study of vitamin A metabolism in prealbumin forms of amyloid disease; 2) the isolation of cDNA clones for serum amyloid A; 3) an investigation of stair climbing in arthritis; and, 4) a study of the difficulty dimension in functional assessments.

MAC education efforts will continue to be aimed at a broad spectrum of arthritis health professionals in conjunction with the Schools of Medicine, Nursing and Allied Health Professions of Boston University. Specific projects in the education component will include an evaluation of the current status of house officer education in rheumatology at internal medicine and family practice residency programs, a study of the effects of a targeted training program on interpersonal skills of physical therapy

students and an investigation of coping in chronic arthritis.

Activities in the community/HSR component of the MAC will continue to focus on the inner-city community in conjunction with the Department of Health and Hospitals of the City of Boston. Seven specific community/health services research projects are proposed: 1) a project to modify the Arthritis Impact Measurement Scales for use in clinical practice; 2) a project to develop a computer-based community network for clinical rheumatology trials; 3) an inner-city nursing home project combining outreach and data collection for this important population; 4) a study of the rheumatology referral behavior of general internists and family practitioners; 5) an epidemiologic study of osteoarthritis in conjunction with the Framingham Heart Study; 6) an epidemiologic study of oral contraceptives and rheumatoid arthritis in conjunction with an established drug epidemiology group; and, 7) an investigation of the relationship between stressful life events and disease activity in rheumatoid arthritis.

Two core units are proposed: an Amyloid Studies Core Unit and a Research and Evaluation Support Core Unit. These core units will support numerous investigations in areas of special interest to this center.

Occupational Role Dysfunction in Illness: Comparisons with Normative Data

F. Oakley

National Institutes of Health, Bethesda, MD 20892

Sponsor: National Institutes of Health

Progress—The Role Checklist is currently used by the Occupational Therapy Service. The purpose of this project is to determine if the Role Checklist can discriminate among subjects with various diagnoses. The data generated from this project will also be examined against pre-existing data from a normal population to determine if the Role Checklist can discriminate between this sample and a normal

population. The subject population will include inpatients and outpatients between the ages of 18 and 90, who have been referred to the Department of Rehabilitation Medicine, Occupational Therapy Service.

To date, data on 80 subjects has been gathered. A total of 400 subjects is required with 50 from each of the following diagnostic categories: cancer, cystic

fibrosis, eating disorders, major affective disorders, neuromuscular disorders, rheumatoid arthritis, schizophrenia, and systemic lupus erythematosus.

Thus far, approximately 57 subjects have come from the NIMH units with the remainder from the other seven categories.

Multipurpose Arthritis Center: Problem-Oriented Educational Program for Arthritis Using Aerobic-Type Exercise

Susan G. Perlman

Northwestern University Medical School, Chicago, IL 60611

Sponsor: National Institutes of Health

Purpose—This Multipurpose Arthritis center (MAC) proposal engages scholars and scientists from various schools and departments of Northwestern University and from the community in a comprehensive arthritis program. Five feasibility projects are proposed: cell cytotoxicity in rheumatoid arthritis; phenytoin modulation of collagen and collagenase synthesis in synovial cells and effect on macrophages; connective tissue constituent immunogenicity in juvenile chronic arthritis; synovial pathology in early osteoarthritis; and analysis of osteoarthritic and rheumatoid bone for use in prosthesis design. These projects will support new young scientists as well as allow three senior scientists to extend or redirect their work.

The second area of focus is an interdisciplinary educational program, utilizing a problem solving approach, aimed at both professionals and patients. The three projects proposed are: train and evaluate rheumatology fellows as teachers of medical residents using a new curriculum to be developed in outpatient musculoskeletal disease; evaluation of a problem-oriented, aerobic-like exercise program for arthritics; and the use of a discussion group format to enhance problem solving skills in the older os-

teoarthritic. The interdisciplinary team includes professional educators, a medical education evaluator and health professionals at the medical school.

The third area of focus, community and health services research, draws upon a strong base of community involvement combined with the research excellence of Northwestern's Center for Health Service and Policy Research (CHSPR). Three interrelated projects explore various aspects of knee pathology. The first will develop and validate a measure of outcome for a subsequent comparative study. The second will examine the costs of treatments for osteoarthritis of the knee. The third builds upon the work of the earlier two to compare costs and efficacy of arthroscopic surgery and alternatives. Three additional projects add breadth to the research agenda focusing upon musculoskeletal impairment in the elderly, status of families with juvenile arthritic children and a multi-center study of Social Security payment allocation systems.

The Biostatistics and Data Management Core will provide individual project technical assistance as well as database management for a computerized case-finding patient index.

Study of Behavioral Aspects of Rheumatoid Arthritis

Kenneth A. Wallston

Vanderbilt University, School of Nursing, Nashville, TN 37240

Sponsor: National Institutes of Health

Progress—The long-term objective of this project is to gain a fuller understanding of the behavioral aspects of rheumatoid arthritis (RA), a chronic condition which affects over 5 million persons in the U.S. and is a leading cause of disability. The

major question to be explored is why and how do some persons with RA manage to cope very effectively with this disease, while others appear to become helpless in the face of it? Specifically, this investigation aims to investigate longitudinally the

health and illness behaviors of a sample (panel) of persons with RA to determine the extent and developmental course of learned helplessness and active coping in persons with this condition. This investigation will lay the groundwork for future interventions aimed at helping persons with RA cope with their illness.

A panel of 360 patients with RA ranging from those newly-diagnosed to those who have had the condition from 5-6 years will be studied at 6-month intervals over a 3 to 3-and-a-half year period via mailed questionnaires and/or telephone interviews. Among the instruments already developed for this project are measures of arthritis-specific attitudes, locus of control beliefs, depressive effect, values,

health and illness behaviors, and functional capacity. These measures will be administered repeatedly over the course of the study to ascertain changes in behavior and its psychological concomitants. This design was chosen to provide data over the first 10 years of a person's history with RA. Multiple regression analyses are planned to test theoretical models linking arthritis history and experience variables to indicators of learned helplessness or coping which, in turn, will be regressed upon health and illness behaviors and health outcomes. In addition to testing models, these data will provide a wealth of systematically gathered descriptive information to greatly expand our knowledge of RA.

UCSF Multipurpose Arthritis Center: Community Component—Studies Using a Panel of Rheumatoid Arthritis Patients

Edward H. Yelin

San Francisco General Hospital and University of California, San Francisco, CA 94110

Sponsor: National Institutes of Health

Purpose—The major objectives of the Multipurpose Arthritis Center at the University of California, San Francisco are: 1) to conduct basic research in areas related to the etiology and pathogenesis of rheumatic diseases (e.g., mechanisms of immunoregulation, heterogeneity of lymphocytes and monocytes, genetic control of immune responses, molecular mechanisms of lymphocyte activation, regulation of natural killer cell activity, cell biology and chemistry of inflammation); 2) to develop and evaluate new methods for the prevention, diagnosis, and treatment of rheumatic diseases (e.g., lung disease and altered susceptibility to infection in patients with systemic lupus erythematosus); 3) to conduct research into the health care of patients with rheumatic diseases (e.g., health care costs, disability, utilization of medical services); 4) to train biomedical scientists, physicians, and other health professionals; 5) to

conduct education programs for physicians, allied health professionals, and patients; 6) to devise and test more effective ways to educate health professionals and patients (e.g., staff of home health agencies, arthritis care and education in nursing homes, teaching methods in joint protection); and, 7) to work with local, state, and national organizations for the purpose of developing and applying new knowledge.

Progress—To meet these objectives, comprehensive programs in Research, Education, and Community/Health Services Research have been developed at the three major teaching hospitals of the University of California, San Francisco (i.e., Moffitt-Long Hospital, San Francisco Veterans Administration Hospital, San Francisco General Hospital) as well as in the Schools of Medicine and Nursing.

Benefit and Cost Comparison Between a Coordinated Team Care Approach and a Traditional Office Based Approach to Outpatient Management of Rheumatoid Arthritis

Rowland W. Chang, M.D., M.P.H.; Judith Falconer, Ph.D.; Caroline K. Ross, Sc.D.; Larry M. Manheim, Ph.D.; Alan R. Dyer, Ph.D.; Judith A. Sutin, M.D.; Frank R. Schmid, M.D.

Northwestern University Medical School, Chicago, IL 60611; Rehabilitation Institute of Chicago, Chicago, IL 60611; Northwestern University Multipurpose Arthritis Center, Chicago, IL 60611

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—Although many advocate a multidisciplinary team approach to the care of rheumatoid arthritis patients, there are few studies on the relative efficacy or costs of such an approach. This project is a controlled study of a coordinated team care program for ambulatory rheumatoid arthritis (RA) patients at the Rehabilitation Institute of Chicago. This program will be compared to a matched (age, sex, ARA functional class) sample of patients drawn from the Northwestern Medical Facility Foundation Arthritis Section's practice, an example of a traditional office-based program. Functional status and costs, both direct and indirect, are the primary outcomes of this 5-year study of a least 60 patients.

Previous studies have noted some improvement in groups of RA patients who have participated in team-care programs involving various combinations of rehabilitation specialists. One methodologic difficulty that has been noted is the relatively short follow-up time of the previous studies. That has limited the assessment of efficacy to only the short term, with no opportunity to examine long-term benefits. This study will follow patients for at least 2 years (some as long as 4 years) to better assess the long term effects and costs of an interdisciplinary team care program.

Progress—The Rehabilitation Institute of Chicago's Arthritis Team has representation from Rheumatology, Physiatry, Orthopedic Surgery, Nursing, Social

Work, Physical Therapy, Occupational Therapy, Clinical Psychology, and Vocational Rehabilitation. Patients are initially screened by a physician, a nurse, a social worker, and jointly by a physical and occupational therapist. A team meeting is held to generate a care plan and to implement any other appropriate referral. Team meetings are then held on a quarterly basis to update team members on progress and problems and to make revisions of the care plan as needed.

Measured outcomes of this comparative study include portions of the Arthritis Impact Measurement Scales, the Sickness Impact Profile, the Jebsen Hand Function Tests, the fifty-foot-walk time, and subjective assessments by the patient and a blinded rheumatologist. Economic outcomes include direct and indirect costs aggregated using a variety of modern methodologies.

Publications Resulting from This Research

A Controlled Trial of Rehabilitation Team Care for Outpatients with Rheumatoid Arthritis: Methodologic Issues. Chang RW, Falconer J, Ross C, Sutin JA, Dyer AR, Manheim L, Schmid FR, *Arthritis Rheum* 29:S62, 1986.

Observed Versus Self-Report Measures of Functional Status in Arthritis Rehabilitation Research. Chang RW, Falconer J, Ross C, Sutin J, *Arch Phys Med Rehab* 67:693, 1986.

A Controlled Trial of Rehabilitation Team Care for Outpatients with Rheumatoid Arthritis: Preliminary Analysis. Chang RW, Falconer J, Ross CK, Sutin JA, Dyer AR, Carpino C, Siegel ME, Tran N, Schmid FR, *Arthritis Rheum* 30(4S):S45, 1987.

C. Low Back Pain

Myoelectric Analysis of Human Spine Function: Myoelectric Measurement of Human Muscle Endurance

Vert Mooney, M.D.; George V. Kondraske, Ph.D.; Tom G. Mayer, M.D.; Timothy Carmichael, M.S.
University of Texas Health Science Center at Dallas, Dallas, TX 75235 and University of Texas at Arlington,
Arlington, TX 76019

Sponsor: VA Rehabilitation Research and Development Service; Division of Orthopedics, University of Texas Health Sciences Center at Dallas

Purpose—Stimulated by a number of reports which have shown changes in the spectral moments (mean and median power frequency) properties of EMG signals during sustained isometric contractions, we have, for the past 6 years, been investigating such changes in several muscle groups with special attention to clinical applications. A primary interest is in the use of the technique to obtain information about low-back pain patients which would otherwise be unavailable. Our initial work progressed to the point where a prime objective was to characterize the changes in spectral moments which can be observed with a single measurand (for example, a time-constant or slope measure). We believe this is an essential step for clinical applicability of the methodology. Thus, much like a strength measurement or blood pressure measurement, norms could be established and an individual's results could be compared to appropriate norms to determine physiologic integrity.

Progress—To date our work leads us to the following conclusions: 1) measurands which would appear to be useful based on implications of previous reports (such as percent change in spectral moment, absolute change, or time-constant derived from curve fitting with a simple exponential model) show considerable variability in normal populations when test administration procedures are tightly controlled; 2) these measurands derived in populations where different fatigue characteristics might be expected (orthopedic patients, highly trained athletes) exhibit behavior which is not significantly different from established norms; and, 3) based on results from

collective studies in which the monitored change in spectral moments are quantified, clinically usable discriminating power is minimal.

Results—Clearly, spectral moment changes do reflect important physiologic processes. Our results suggest that more accurate models of these processes are required in order to be able to define measurands which would be clinically sensitive indicators of muscle endurance. These conclusions temper the initial optimism which is raised upon connection of electrodes to a muscle and observation of the spectral moment changes during sustained contractions (i.e., an activity which appears to be fatiguing). In fact, we find that the quantitated change in spectral moment characteristics is a more predictable indicator of load level across different subject populations than it is an indicator of endurance. We emphasize that we do not recommend discarding the technique, as changes in the spectral moment are reliable and must reflect important underlying processes. Rather, attention must be focused to understand exactly what spectral moment changes reflect relationships to other experimental variables, definition of quantitative characterization of the changes based on conceptual models, and the acquisition of evidence in support of clinical discriminating power based on defined quantitative measures.

Implications—These findings suggest that a cautiously optimistic perspective be placed on the use of myoelectric spectral analysis methods in clinical rehabilitation applications at the present time.

Evaluation of Psychophysiological Ways to Assess Chronic Low Back Pain

Richard A. Sherman, Ph.D.; Glenda M. Bruno, R.N., M.S.; John G. Arena, Ph.D.; Roberto Barja, M.D.
Eisenhower Army Medical Center, Fort Gordon, GA 30905 and Veterans Administration Medical Center, Augusta, GA 30910

Sponsor: VA Rehabilitation Research and Development Service; Department of Clinical Investigation of the US Army

Purpose—The goal of this project is to evaluate the effectiveness of psychophysiological ways to assess low back pain.

Progress—Subjects with low back pain are given a complete physical examination and other objective medical tests. They are then interviewed by a psychologist and given both a standard and a specially modified Minnesota Multiple Personality Inventory (MMPI). They then participate in 4 weekly muscle tension and heat pattern recordings while experiencing various intensities of low back pain.

Preliminary Results—This study is still in its early stages. We have already found that subjects with low back pain do not change many of their MMPI responses depending on whether or not they are in

pain when answering the questions. Too few subjects have completed participation for firm conclusions. To date, we have not found clear relationships between low back or leg thermograms and intensity or diagnosis of low back pain. Paraspinal muscle tension correlates well with pain intensity regardless of diagnosis.

Future Plans/Implications—We will continue the study until sufficient subjects are completed to permit us to draw clear conclusions from the data.

Publication Resulting from This Research

Thermographic Correlates of Chronic Pain: Analysis of 125 Sequential Subjects Incorporating Evaluations by a Blind Panel. Sherman R, Barja R, Bruno G, *Archives of Physical Medicine and Rehabilitation* 68:273-279, 1987.

Low Back Pain Studies

John W. Frymoyer, M.D.; Malcolm H. Pope, Ph.D.; Raymond L. Milhous, M.D.
Vermont Rehabilitation Engineering Center, Burlington, VT 05401

Sponsor: National Institute on Disability and Rehabilitation Research

Progress—Currently under way are several research projects, each comprising several studies, in the following areas.

1) **Epidemiologic Analyses, Prediction of Disability and Assessment of Rehabilitation.** These studies involve the assessment of a wide range of back pain-related risk factors (e.g., occupational, psychological, recreational, environmental, anthropometric, and radiographic) and the development of a reliable information-gathering system in order to improve diagnosis and treatment. Both organic and functional correlates of low back pain are considered in developing a multi-attribute utility model for predicting low back pain impairment and disability. This project has led to the creation of a questionnaire for predicting disability early in the course of the disease. This is a crucial step in developing early, definitive treatment programs to prevent chronic disability

which accounts for 85 percent of the total costs associated with low back pain in this country. Other areas of investigation are assessment of costs associated with low back pain and relative cost-benefit ratios for various rehabilitation techniques.

2) **Mechanical and Electrical Rehabilitation.** Research on spinal orthoses has led to the development of a new internal fixation device, the Vermont Spinal Fixator, which offers numerous advantages over previous stabilization systems. Thorough studies of various mechanical and electrical outcome measures have been completed. Further biomechanical characterization of several external orthoses and clinical assessment of electrical stimulation, bracing, and other treatment modalities are now underway and should lead to advances in effective treatment and pain reduction.

3) **Seating.** The aim of improved seating in both

static and vibration environments has led to studies of relationships among types of seating, spinal support structures and seated postures. Recommendations arising from studies of vibration in cars, trucks and buses are being incorporated in various vehicular designs. The Center has also recently established a Seating Research Center, which supports research on the mechanics of office seating and offers research and development consultation to chair and office environment manufacturers. The application of new technologies can be expected to reduce low back pain among office and other seated workers.

4) **Vocational Rehabilitation.** To improve the rate of successful return to work after a back injury or period of disability, rehabilitation engineers are investigating workers' functional physical capacities, job task requirements, and the effect (and cost effectiveness) of matching workers and jobs through job selection and modification. Research engineers at the REC also work with industry representatives toward incorporating human factors in worksite and equipment design, in order to minimize the risk of back injuries and to assist the back-injured or handicapped worker in an early and safe return to work.

D. Vascular Disorders

Blood Velocity and Spectra Estimations from Doppler Ultrasound

Don P. Giddens, Ph.D.

Veterans Administration Medical Center, Decatur, GA 30033 and George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Doppler ultrasound is in widespread use as a noninvasive diagnostic modality for cardiac and peripheral vascular disease. Prompt diagnosis and treatment, including follow-up evaluations, are crucial to the middle aged and elderly. Surgical and pharmacological treatment can be effective in returning the patient to reasonably normal and productive function if diagnosis of vessel disease is made prior to a catastrophic episode, such as myocardial infarction or stroke. Present methods of determining blood velocity and Doppler spectra, two vital diagnostic indicators, often suffer from poor resolution and inaccuracies. The present research uses modern methods of signal analysis to provide optimum accuracy in velocity and spectral estimates. The results will improve Doppler diagnostic techniques with existing equipment, and will be applicable to improvements in the new generation of flow color Doppler instruments recently introduced to the noninvasive laboratory. Following the validation of the signal analysis methods, a study will be proposed to implement the techniques in a clinical research program.

Progress—Computer programs that employ autore-

gressive methods of velocity and spectral estimation from pulsed Doppler data have been developed and implemented on the Georgia Tech CYBER computer. These programs have also been installed in the MASSCOMP data acquisition system in the School of Mechanical Engineering. Measurements have been performed on a moving string target device, which provides a constant velocity for calibration of results, and on several flows in laboratory models using an 8-megahertz pulsed Doppler ultrasound instrument. Graphics routines for displaying the results have also been developed. Data processing is in progress in order to determine optimum parameters to improve the analysis methods. The research is on schedule with respect to the proposed protocol.

Preliminary Results—A series of new computer programs for autoregressive data analysis have been developed and checked out. We have also worked on the development of a mathematical model for synthesized Doppler, which can be used to vary parameters more readily and under better control than is possible with experimental data. This synthesized model is approximately 50 percent com-

pleted. Additionally, experiments with the string target device and with several flow systems have provided actual data for analysis. Our results to date indicate that autoregressive estimates of velocity are significantly better than estimates obtained via the usual Fourier methods. Further, estimates of Doppler spectra obtained by autoregressive techniques have considerably less variance than those calculated by FFT algorithms. Thus, the results at this stage are very promising and are providing the improvements we hypothesized.

Future Plans—We plan some further validation studies with the synthesized Doppler model and with flow model experiments in order to establish firmly the improvements and limitations of our techniques. Next, we will make Doppler ultrasound measure-

ments in a compliant model of the human carotid bifurcation and compare our velocity estimation results with those obtained by laser Doppler anemometry, a very accurate instrument but one that cannot be used in noninvasive vascular diagnosis. The carotid models will include simulated plaques so that we may study the flow disturbances created by mild to severe arterial disease. The results of these studies will then serve as a basis for developing a protocol for a clinical research program involving early detection of early carotid arterial disease.

Presentation Resulting from This Research

Fluid Mechanics of Large Arteries. Don P. Giddens et al., presentation at the *New England Doppler Conference*, Durham, NH, May 1986.

A Program for Evaluating the Dysvascular Patient

Bok Y. Lee, M.D., and Lee E. Ostrander, Ph.D.

Veterans Administration Medical Center, Castle Point, NY 12511 and Rensselaer Polytechnic Institute, Troy, NY 12181

Sponsor: VA Rehabilitation Research and Development Service

The Role of Lumbar Sympathectomy to Manage Lower Limb Arteriosclerotic Occlusive Disease—This is an ongoing program in the evaluation of the dysvascular patient with atherosclerotic occlusive disease (ASOD), for purposes of rehabilitation.

Purpose—The program supports the development of quantitative measures for improved assessment of subcutaneous tissue viability when ischemia and/or edema are present. The measures are intended to provide clinically usable criteria to guide the preoperative and intraoperative selection of interventions and to follow the clinical course of the patient during rehabilitation. The proposed studies are to assess the efficacy of measures resulting from three test procedures: orally administered fluorescein as a perfusion indicator, inhaled hydrogen measurement of perfusion, and measurement of mechanical pressure-displacement relationships in tissue.

Progress—The use of orally ingested fluorescein is a new approach which substantially reduces the risk of allergic reaction over that when the dye is ad-

ministered intravenously. The test permits rapid measurements of skin perfusion in localized limb areas. Inert hydrogen gas washout at open sites without skin covering, intra-operatively or following tissue debridement, is possible, since the outer layer is missing which otherwise would inhibit transport of hydrogen from tissue to probe. The advantage of hydrogen for this purpose is that the measurement area can be small, and the hydrogen gas is physiologically inert so that there are no side effects. During the third year of the current program, instrumentation for multiprobe analysis is being designed and assembled. In the proposed study, surface probes are to be developed, extending to a multiprobe arrangement so as to obtain a distribution of readings over a surface. The tissue mechanical measurements are based on instrumentation which is being developed in the current program. Quantitative data is obtained to monitor changes in tissue property associated with edema and with the revascularization compartment syndrome.

With each test, the objective is a convenient instrument package which will permit easy measurement in the clinical environment. Development

and evaluation will proceed in laboratory studies of responses to ischemic and edematous processes, and in some instances to the sequelae of lumbar sympathectomy. Test results will be evaluated for potential in predicting tissue viability in studies of patients with ASOD in the lower extremities. Clinical outcomes will be represented as (Category I) failure due to inconclusive healing or failed healing evidenced by surgical intervention or death; and (Category II) healing, or non-healing but without progression of disease. Testing is done pre- or intraoperatively and postoperatively, and according to schedule in the follow-up period. Results will be compiled for each of the tests in the study to determine the relation of test criteria to sensitivity and specificity in predicting Category I or Category II results. From this information, it is intended to further expand knowledge on the use of the instrumentation and quantitative methods being studied so as to minimize the need for amputation and other loss of mobility and function. The ultimate goal is improved rehabilitation, freedom from pain, reduced healing time and hospital time, while minimizing expense.

Measurement of Edematous Changes During the Revascularization Compartment Syndrome—Edema in the lower limb may occur following revascularization. The edema can lead to the revascularization compartment syndrome, a serious problem in which fluid accumulates in a compartment of the leg. When this occurs, pressures increase within the compartment and blood flow is reduced, leading to ischemia and necrosis. The pressure must be monitored to know when therapeutic intervention is required. The present approach is invasive in which pressure is measured through needle and catheter insertion. We are developing a noninvasive approach to follow the patient during the edematous changes. This approach is based on external tissue mechanical measurement.

Preliminary Results—Preliminary studies in animals show good correlation between pressure changes within the compartment and the external mechanical tissue compliance over the compartment. Preliminary studies in humans show good correlation with the clinical course and good repeatability of results. The new approach promises to be a useful alternative to direct pressure measurement. Since the approach is noninvasive, it reduces risk to the limb.

Use of Cutaneous Pressure Photoplethysmography in Managing Peripheral Vascular Occlusive Disease—A technique for local measurement of cutaneous perfusion pressure (CPP) has been developed. This method provides measurements at multiple points on the limb in the patient with occlusive disease and a variety of symptomatology including claudication, rest pain, gangrene and ulcers. As previously reported, results indicate that the technique can successfully identify the presence of peripheral vascular disease, distinguish among different levels of severity, and aid in determining the optimal level of amputation consistent with wound healing. The technique can also assist in following the patient's course of recovery after reconstructive vascular surgery.

Presently, we are developing quantitative methods for incorporating multiple measurements into a prognostic index. This development will accomplish two purposes. First, it provides a quantitative approach to incorporating multiple measurements. Second, it improves sensitivity and specificity over that which would otherwise be possible with a single measurement.

Fluorometry in Assessing Tissue Viability—The quantitative use of fluorescein dye indicator in predicting tissue viability is being examined in a surgical flap model. Perfusion fluorometry is a method which quantifies tissue fluorescence and replaces subjective visual observation. A light source in the blue wavelengths of 450 to 500 nm is transmitted via a fiber optics pathway to illuminate a selected area of tissue, of 1 cm diameter. The light excites the fluorescein in tissue which emits light in the range from 520 to 660 nm. This light is transmitted via a second fiberoptic bundle to a photomultiplier tube which, with the aid of electronics, provides a direct readout of dye fluorescence. Fluorescence at the skin surface is measured following flap formation and is correlated with viability of the flap tissue at seven days. The perfusion fluorometry technique is expected to prove helpful in the intra-operative assessment of flap viability and in the treatment of pressure sores.

Publications Resulting from This Research

Lumbar Sympathectomy for Toe Gangrene: Long Term Follow-up. Lee BY, Madden JL, Thoden WR, McCann WJ, *American Journal of Surgery* 145:398-401, 1983.
Diagnostic and Surgical Considerations in the Management of

- Compartmental Syndrome.** Lee BY, Brancato RF, Park I, Shaw W, *American Journal of Surgery* 148:383-388, September 1984.
- Chronic Ulcers of the Skin.** Bok Y. Lee (Ed.), McGraw Hill Book Company, New York, NY, 1984. Dr. Lee was also an author of five chapters in the book.
- Cutaneous Pressure Photoplethysmography: A New Technique for Noninvasive Evaluation of Peripheral Arterial Occlusive Disease.** Lee BY, Thoden WR, Madden JL, McCann WJ, *Contemporary Surgery* 25:39-43, November 1984.
- Pentoxifyline Treatment of Moderate to Severe Chronic Obstructive Arterial Disease.** Lee BY, Berkowitz P, Savitsky JP, May GS, Brobst J, McCann WJ, *Journal of Clinical Cardiology* 8, March 1985.
- Peripheral Vascular Noninvasive Measurements.** Lee BY, *Encyclopedia of Medical Devices and Instrumentation*, John Wiley & Sons, Inc., New York, NY (in press).
- Use of Cutaneous Pressure Photoplethysmography in Managing Peripheral Vascular Occlusive Disease: Preliminary Report,** Lee BY, Ostrander L, Thoden WR, Madden JL, *Contemporary Orthopaedics* 13:51-58, 1986.
- Intraoperative Assessment of Intestinal Viability.** Lee BY, Ostrander LE, Silverman D, Thoden WR, Madden JL, McCann WJ, *Connecticut Journal of Medicine* (in press).
- Characterizing Atherosclerotic Lesions by Proton Spectroscopy.** Ostrander L, Frank A, Daoud A, Darcy K, Lee B, presented at the *Fifth Annual Meeting of the Society of Magnetic Resonance*, 1986.
- Effect of Lumbar Sympathectomy on Muscle Blood Flow: Distribution of Perfusion Measured by Hydrogen Clearance in Skeletal Muscle.** Lee BY, Ostrander LE, Thoden WR, Madden JL, *Journal of Rehabilitation Research and Development* 24(3):1-8, 1987.
- Use of Cutaneous Pressure Photoplethysmography in Managing Peripheral Vascular Disease.** Lee BY, Ostrander LE, Thoden WR, Madden JL, *Contemporary Orthopaedics* 30:58-67, 1987.

A Program for Evaluating the Dysvascular Patient (Project Extension)

Bok Y. Lee, M.D.

Veterans Administration Medical Center, Castle Point, NY 12511 and New York Medical College, Valhalla, NY

Sponsor: VA Rehabilitation Research and Development Service (Project #XA086-4RA)

Purpose—This is an ongoing program in the evaluation of the dysvascular patient with atherosclerotic occlusive disease (ASOD), for purposes of rehabilitation. The program supports the development of quantitative measures for improved assessment of subcutaneous tissue viability when ischemia and/or edema are present. The measures are intended to provide clinically usable criteria to guide the pre-operative and intraoperative selection of interventions and to follow the clinical course of the patient during rehabilitation. The proposed studies are to assess the efficacy of measures resulting from three test procedures: orally administered fluorescein as a perfusion indicator, inhaled hydrogen measurement of perfusion, and measurement of mechanical pressure-displacement relationships in tissue.

The use of orally ingested fluorescein is a new approach which substantially reduces the risk of allergic reaction as opposed to when the dye is administered intravenously. The test permits rapid measurements of skin perfusion in localized limb areas. Inert hydrogen gas washout at open sites without skin covering, intraoperatively or following tissue debridement, is possible since the outer layer is missing which otherwise would inhibit transport of hydrogen from tissue to probe. The advantage of hydrogen for this purpose is that the measurement

area can be small, and the hydrogen gas is physiologically inert so that there are no side effects. During the third year of the current program, instrumentation for multiprobe analysis is being designed and assembled. In the proposed study, surface probes are to be developed, extending to a multiprobe arrangement so as to obtain a distribution of readings over a surface. The tissue mechanical measurements are based on instrumentation which is being developed in the current program. Quantitative data is obtained to monitor changes in tissue property associated with edema and with the revascularization compartment syndrome.

With each test, the objective is a convenient instrument package which will permit easy measurement in the clinical environment. Development and evaluation will proceed in laboratory studies of responses to ischemic and edematous processes, and in some instances to the sequelae of lumbar sympathectomy. Test results will be evaluated for potential in predicting tissue viability in studies of patients with ASOD in the lower extremities. Clinical outcomes will be represented as (Category I) failure due to inconclusive healing or failed healing evidenced by surgical intervention or death; and (Category II) healing, or nonhealing but without progression of disease. Testing is done pre- or

intraoperatively and postoperatively, and according to schedule in the follow-up period.

Results will be compiled for each of the tests in the study to determine the relation of test criteria to sensitivity and specificity in predicting Category I or Category II results. From this information, it is intended to further expand knowledge on the use

of the instrumentation and quantitative methods being studied so as to minimize the need for amputation and other loss of mobility and function. The ultimate goal is improved rehabilitation, freedom from pain, reduced healing time and hospital time, while minimizing expense.

Evaluation of Pressures Applied by Elastic Dressings

Subrata Saha, Ph.D., and J.A. Albright, M.D.

Louisiana State University School of Medicine, Shreveport, LA 71130

Sponsor: Chesebrough-Pond's Inc.

Purpose—Elastic stockings are often used to treat edema and swelling and varicose veins, as well as to control hypertrophic scar in burn patients. Recently it has been suggested that compression stockings may also be effective in preventing thromboembolism following surgery. In most applications, the stockings need to apply a graduated compression on the limb to facilitate the venous and lymphatic flow. However, the therapists often use various compression dressings without any direct measurement of the applied pressure. The objective of this study is to compare the pressures applied by different sizes and types of dressings on lower limbs of different diameters. The change in pressure with time was also measured. The effectiveness of pressure dressings in reducing swelling and edema in patients is also being evaluated.

Progress—In our laboratory study, we compared the pressures applied by ProSorb (Chesebrough-Pond's Inc.) and Tubigrip (Seaton Products) dressings on cylinders of various diameters. The pressure was monitored by a specially designed flexible pressure transducer consisting of a pressure switch, a solid state pressure transducer, and a digital readout in mm of Hg (Clinical Technology Corp).

Pressure readings were also taken on a limited number of patients with post fracture edema and lacerations. The reduction in swellings was measured by using a liquid displacement method (Volumeters Unlimited), as well as measuring the change in circumference.

Results—Our results clearly show that the applied pressure depended on the geometry of the limb and it was highest (measured at lateral malleolus) at the ankle. As expected, the pressure also was a function of the type and size of the elastic stocking. When we monitored the pressure applied by a stocking on a cylinder of fixed diameter, we found that the pressure decreased slightly with time, indicating stress relaxation of the stocking material. The drop in pressure was higher during the first few hours and then it slowly stabilized with time.

If the same size elastic stocking was applied on cylinders of increasing diameters, the applied pressure increased more rapidly than predicted by theoretical calculation, assuming a linear elastic behavior of the fabric material. This suggests that the stress-strain behavior of the stocking material is highly nonlinear due to the woven nature of the fabric.

Based on our study on a limited number of patients, we found the pressure dressings to be efficacious in controlling edema and swelling. We also found the volume change as measured by the displaced liquid to be a more reliable indicator of the reduction in swelling than the commonly used clinical method of measuring the circumference of the limb. The patients found the ProSorb dressing to be more comfortable and to apply more uniform pressure compared to other types of dressings.

Future Plans/Implications—This study is being continued to determine the optimum pressure levels necessary for various types of clinical problems.

Publications Resulting from This Research

Evaluation of Pressures Applied by Elastic Dressing. Saha Subrata, Saha Sukumar, Albright JA, Whelahan T, Norton K, *Proceedings of the 37th Annual Conference of Engineering in Medicine and Biology*, Vol. 26, 229, 1984.

Application of Pressure by Elastic Bandages. Saha S, Saha S, and Albright JA, *Biomedical Engineering III: Recent Developments*, (L Sheppard, ED.), Pergamon Press, 145-147, 1984.

Postoperative Thromboembolism in Surgical Patients

Edwin W. Salzman

Beth Israel Hospital, Boston, MA 02215

Sponsor: *National Institutes of Health*

Purpose—A series of controlled prospective clinical trials with supporting laboratory investigations in the pathophysiology of thrombotic states and related conditions, and the pharmacology of new antithrombotic and hemostatic drugs will be conducted.

Progress—The principal clinical trials, which are already in progress, include: 1) study of a hemodynamically optimized system for external pneumatic compression of the lower limbs to prevent venous thrombosis in patients undergoing neurosurgical operations; 2) investigation of the effective-

ness and safety of therapy of established venous or arterial thromboembolism with a heparin preparation of low molecular weight and high antithrombin affinity; 3) trial of the prevention of venous thromboembolism in patients with fractures of the hip by administration of a heparin-like compound (Organon 10172); and, 4) administration of DDAVP to improve hemostasis in patients undergoing cardiopulmonary bypass and exploration of the role of von Willebrand's factor in the hemostatic defect in such patients.

Characterizing Atherosclerotic Lesions by Proton Spectroscopy

Lee E. Ostrander, Ph.D.; Bok Y. Lee, M.D.; K. Darcy, B.S.

Rensselaer Polytechnic Institute, Troy, NY 12181 and Veterans Administration Medical Center, Castle Point, NY 12511

Sponsor: *None Listed*

Purpose—There have been reports of *in vivo* imaging from atherosclerotic lesions in which image intensities are brighter in the plaque when compared with the surrounding uninvolved vessel wall tissue, presumably due to the presence of lipids in the plaque. The purpose of the present study has been to obtain proton spectra characteristic of atherosclerotic lesions in order to eventually predict imaging characteristics as related to pathology.

Progress—Work to date has focused on: 1) determining sample handling procedures and pulse sequences; 2) identifying characteristics of spectra associated with atherosclerotic lesions, in contrast to uninvolved tissues; 3) relating spectral peaks to analyzed chemical constituents of the vessel wall and lesion; and, 4) considering the implications of

results for *in vivo* studies.

Data are being collected on a Varian XL-200 system (200 MHz) for 90 degree pulses and for spin echo sequences. Tetramethylsilane diluted in deuterated chloroform is used as a reference. Spectra were obtained from post-mortem aorta wall and serum. Changes with time and temperature, effects of storage in saline, and of storage by freezing have been observed. Spectra in these studies to date show relatively little dependence on the aforementioned handling conditions over the range of parameters investigated. All samples show the characteristic peaks which are generally described as the methylene and methyl groups of lipids. Other peaks are clearly present and values for T1 and T2 have been obtained.

We anticipate that an optimal differentiation be-

tween lesion and nonlesion can be determined for the *in vivo* mode, once relaxation and spectral characteristics are known and once pulse sequences are selected to match these characteristics.

Publications Resulting from This Research

Characterizing Atherosclerotic Lesions by Proton Spectroscopy.

Ostrander LE, Frank AS, Daoud A, Darcy K, Lee B (abstract), *Fifth Annual Meeting of the Society of Magnetic Resonance*, Montreal, 1986.

Preliminary ^1H NMR Studies of Human Aorta Wall Containing Lesions at 100 and 200 MHz. Schwartz H, Ostrander LE, Darcy K, Frank AS, Daoud A (abstract), *Gordon Conference on Magnetic Resonance in Biology and Medicine*, 1986.

XIII. Head Trauma and Stroke

The Application of Microcomputers for the Treatment of Aphasic Adults

Felice L. Loverso, Ph.D., and Thomas E. Prescott, Ph.D.

Harry S. Truman Veterans Administration Hospital, Columbia, MO 65201 and Veterans Administration Medical Center, Denver, CO 80220

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The use of microcomputers in rehabilitation of brain damaged patients continues to win popularity in some clinical settings. Cost effectiveness, operational efficiency, and increased treatment-time allocations without additional human resources are the high tech features which bolster their acceptance and application. Yet database research in speech/language pathology concerning treatment efficacy remains sparse. In this age of high tech applications to almost every phase of our professional lives, there appears an urgent necessity to know the efficacy of treating patients with microcomputers. The field presently lacks convincing data as to the efficacy of using microcomputers for the rehabilitation of aphasic adults. It is unfortunate, however, that many clinicians are getting into the computer business without collecting this efficacy data first. The purpose, then, of the present study is to answer the following question: are microcomputers more effective in teaching a criterion performance than the same procedure presented by a clinician?

Progress—The study is being made up of 20 chronic aphasic patients who have sustained a single lesion to the left hemisphere. Each aphasic person within this study population will be in the mild-to-moderate range of aphasic severity. To study treatment effectiveness, an alternating treatment design with multiple probes (single case), is utilized. By using this type of design, baseline performance, the effects of treatment, maintenance of behavior, and generalization can easily be viewed. All patients receive two modes of treatment (clinician and microcomputer) daily, in a rapidly alternating fashion.

The microcomputer and clinician treatment packages are identical in terms of types of stimuli, modality and randomization of presentation, type of feedback, and scoring. The treatment itself is a

well established protocol which has been demonstrated to be effective with this population of patients. In this treatment approach, verbs are presented as pivots and wh-questions provide strategic cues to elicit sentences in an actor-action-object framework. There are six hierarchical levels to this program, ranging from copying a subject + verb combination to self-generation of subject + verb + object sequences. This treatment paradigm, in the traditional patient/clinician environment, is now being used nationally with adult brain-injured patients as well as with children with specific language and learning disabilities.

Preliminary Results—As of June 1, 1987, 12 of the 20 patient/subjects have been entered into the study and have completed the treatment package. For the subjects studied, the clinician-alone mode of treatment was more efficient in bringing most aphasic patients to criteria than was the computer mode. For those patients who responded better to the clinician mode, it took approximately twice as many sessions with the computer versus the clinician to complete the treatment package. It is noteworthy that although the clinician was far more efficient in terms of total visits, the microcomputer was shown to be an effective treatment tool for this particular treatment protocol. Maintenance of behaviors were observed across all clinician treatment levels and four of the six treatment levels via computer presentation. Generalization to standardized language tests was also observed. Statistically significant ($p < 0.01$) improvement was noted between standardized overall test scores for treatment levels compared to the stable baselines in the clinician mode of treatment. These gains have been maintained by the patient/subjects for three months following termination of the treatment.

For those patients who showed no significant

differences ($p < 0.05$) between modes of treatment, equal number of visits for each type of treatment were recorded. For these patients, maintenance of behaviors were observed as well as generalization to standardized language tests following each overall level. It does appear, however, that the treatment results for this group of patients is related to the severity and type of aphasia of each patient. Preliminary results indicate that some mild nonfluent aphasic adults show little difference in the treatment modes investigated in this study.

In addition to providing comparative results of clinician versus microcomputer, the present study also systematically replicates our previous work for the clinician mode of treatment, indicating this treatment approach is a viable protocol in the rehabilitation of brain injured aphasic adults.

Future Plans/Implications—Research needs to continue measuring the effects of this program with more subjects, more types of aphasia, and more severity levels of this disorder for both clinician and

computer modes of treatment. Additionally, cueing hierarchies for eliciting the actor-action-object framework needs to be explored further along this task continuum. This will enable the patient to receive the most efficacious cueing stimuli to maximize his/her output. These future efforts should make available a reliable, effective treatment program for both the microcomputer and clinician modes of treatment in the rehabilitation of aphasic adults to other facilities with similar case loads.

Publications Resulting from This Research

Below the 50th Percentile: Application of the Verb as Core Model.

Selinger M, Loverso FL, Fuller K, *Clinical Aphasiology Conference*, Minneapolis, MN, BRK Publishers, 1987.

Unfounded Expectations: Computers in Rehabilitation.

Loverso FL, *Aphasiology, An International, Interdisciplinary Journal*, Drs. Code and Muller (Eds.), Taylor & Francis Ltd., Publishers, 1987.

Data Versus Intuition in Using Micro-computers for Aphasia Rehabilitation.

Loverso FL, Prescott TE, presented and published abstract from the American Speech-Language-Hearing Association National Convention, Detroit, MI, 1986.

Biomechanical Measurements for Quantitative Assessment and Diagnosis of Dysphagia

Narender P. Reddy, Ph.D.; Enrique P. Canilang, M.D.; Manikchand B. Rane, B.E.;
Judy Casterline, M.A., CCC-S.P.

Department of Biomedical Engineering, University of Akron, Akron, OH 44325 and Rehabilitation Engineering Research Laboratory, Edwin Shaw Hospital, Akron, OH 44312

Sponsor: Edwin Shaw Hospital Foundation

Purpose—Dysphagia is a disorder of swallowing resulting from neurological impairment and presents a major problem in the comprehensive rehabilitation of patients with stroke and other head injuries. Due to the lack of quantitative measurements of the strength of associated tissues, the course of recovery in the present clinical practice is tedious, and depends on trial and error. There are two important stages of swallowing: an oral phase and a pharyngeal phase involving contractions of the pharynx in coordination with the oral phase. We have developed procedures for quantitative measurement of these two phases of swallowing.

Progress—We have identified and developed techniques to measure several biomechanical parameters which aid in the quantitative assessment of the oral musculature in dysphagia. These parameters in-

clude: 1) lip closure pressure; 2) lip interface shear force; 3) tongue thrust in forward, backward and the two lateral directions; and, 4) swallow pressure.

We have placed two ultra-miniature accelerometers on the outside of the throat at a distance apart. In addition, we have monitored the swallow pressure with a catheter placed at the base of the tongue and connected to a pressure transducer. In both normal subjects and dysphagia patients, we have measured acceleration and swallow pressure simultaneously.

Preliminary Results—We have found statistically significant differences in the above parameters measured in normal and dysphagia patients. The first two parameters characterize the strength of the cheek muscles and the last two parameters characterize the tongue thrust. In current clinical practice, the strength of the oral musculature is assessed using

tongue depressors and "lollipops." The biomechanical parameters devised in the present investigation can aid the physician to objectively assess the dysphagia patient during recovery.

In normal individuals there was no time lag between the appearance of the pressure wave and the appearance of the acceleration wave characteristic of swallowing. In patients with loss of coordination of the swallowing mechanism, we have found significant lag times between the acceleration and pressure waveforms. Also, the acceleration wave form can reveal the coordination of the pharyngeal muscle contraction.

Future Plans/Implications—The biomechanical parameters identified and the measurement techniques developed in this study can be used for quantitative evaluation of the patient and for patient training to speed up the recovery process.

In the current rehabilitation practice, the pharyn-

geal phase and coordination are assessed using video-fluoroscopy (radiography) which is often very expensive. Our results on the dysphagia patients were consistent with the video-fluorography findings. Acceleration, when measured simultaneously with the swallow pressure measurement, gives a quantitative picture of the coordination of the swallowing mechanism and can be used in dysphagia diagnosis. However, a study on a larger population of patients is necessary.

Publications Resulting from This Research

Biomechanics in Dysphagia. Reddy NP, Costarella BC, Grotz RC, International Conference of Medical and Biological Engineering, Espoo, Finland, August, 1985; *Medical and Biological Engineering and Computing*, 23(S2):1243-1244, 1985.

Biomechanical Measurements for Assessment and Diagnosis of Dysphagia. Reddy NP, Rane MB, Canilang EP, Casterline J, *IEEE Ninth Annual EMBS Conference*, Boston, MA, 1987.

Long-Term Effects of Topical Anesthesia in Stroke Patients: Measurement and Analysis of Neurophysiological Reflexes

Kyle Richard, B.S.; Serge H. Roy, M.S.; Carlo J. De Luca, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: Liberty Mutual Insurance Company

Progress—Tests measuring the H-Reflex and Achilles Tendon Reflex were previously performed on nine patients suffering from stroke. The H-Reflex consisted of measuring the response of the muscle induced by an electrical stimulus. The recovery of the H-Reflex was determined by measuring the response to two identical electrical stimuli with a known time interval. The stimuli were applied to a nerve supplying the gastrocnemius and soleus muscle of the leg. The Achilles Tendon Reflex was measured by obtaining the muscle response to a short, mechanically induced, stretch of the muscle. By comparing the results of these reflexes, the activity of motoneurons was measured. Measurements were obtained during time periods before or

following the application of topical anesthesia or a placebo spray.

To facilitate analysis of these data, new software utilizing artificial intelligence techniques was developed. Prior to the development of this software, an extensive amount of time was necessary to determine reflex parameters. At the present time, we are able to decrease the analysis time significantly and increase the reliability of our estimates. The software aids in pre-screening the data, recognizes particular reflexes, and then calculates specific parameters. The data analyzed to date suggest that behavior of the long-term effect of topical anesthesia on the motor output of patients suffering from stroke is similar to the short-term effect.

Development and Evaluation of a Videotape Teaching Module for Nursing Students in the Clinical Setting

Nathaniel H. Mayer, M.D.; Carol A. Mackenzie, M.S.; Ronald I. Kalstein, M.Ed.; Charlene McCoy, RN, BSN, CRRN; Ann Weaver, OTR/L

Jerome J. Drucker and Sylvan W. Drucker Brain Injury Center for Comprehensive Rehabilitation, Research and Training of Moss Rehabilitation Hospital, Philadelphia, PA 19141

Sponsor: National Institute on Disability and Rehabilitation Research; Genesis Foundation, Providence, Rhode Island

Purpose—The purpose of this project is to develop and evaluate an instructional videotape for nursing students working in the inpatient brain injury unit. In this clinical setting, nursing students often assist patients in performing activities of daily living, such as self-feeding. Yet traditional nursing education affords little exposure to brain-injured patients, or to the techniques that are required to assist these patients in learning to perform daily activities.

Progress—This project is being conducted in two phases: 1) development of the instructional videotape based on observations of student nurse-patient interactions in the actual clinical setting; and, 2) evaluation of the videotape using a randomized control group design with nursing students as subjects.

Development of the 20-minute videotape is based on the Cyrs model of systematic instructional design. Based on this model, learning objectives and content of the instructional videotape were taken directly from videotaped observations of nursing students doing self-feeding with actual patients. These observations revealed a number of teaching errors, including: doing too much for the patients; causing and/or not eliminating distractions; and using either verbal or nonverbal cues ineffectively. The instructional videotape addresses these and other errors using simulated self-feeding scenes. It also gives an introduction to brain injury and its diffuse effects on performance and learning ability.

Evaluation of the videotape will be based on two

measures: 1) a 15-item written knowledge test; and, 2) a 20-minute performance test using a simulated patient. Performance tests will be videotaped, then rated by expert reviewers using a 15-item checklist of performance objectives. Subjects who view the instructional videotape will be compared to a control group who receive the usual brief verbal instructions on how to approach a brain-injured patient.

Preliminary Results—The development phase of this project is now complete. Results of this phase point to both the validity and the complexity of producing an instructional videotape in the clinical setting. Complexity factors include: variability of brain-injured patients; heterogeneity of nursing students; and unpredictability of the clinical environment of the brain injury unit from day to day. However, by incorporating these factors, the instructional validity of the videotape was clearly increased.

Data from the evaluation phase will indicate the instructional effectiveness of this videotape. These data will also demonstrate the validity and reliability of the dual knowledge-performance testing process in the clinical setting.

Future Plans/Implications—Based on these results, the investigators will consider the use of videotape as an instructional tool in skill areas other than self-feeding. As such, videotape may prove a valuable and versatile tool for training nursing students, new staff, families, and others who serve as both caretakers and teachers of brain-injured patients.

Computer-Aided Device Evaluation

Cheryl Goodenough-Trepagnier, Ph.D., and Michael J. Rosen, Ph.D.
New England Medical Center, Boston, MA 02111

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—The goal of this project is the testing of clinical feasibility and the further development in

response to testing results, of the Tufts-MIT Prescription Guide, developed by Dr. Goodenough-

Trepagnier and Dr. Michael J. Rosen of the Massachusetts Institute of Technology under a research and development contract from the National Institute of Neurological and Communicative Disorders and Stroke. This system is a computer-driven procedure involving cognitive, sensory needs and motor assessment of the client, and in-laboratory device assessment. Analysis software incorporated in the system then operates to produce scores representing, on the one hand, a representation of the relative overall benefit which each device resident in the system files offers for the client being evaluated; and on the other hand, scores representing predications of the maximum communication rate the client could achieve with each of these devices.

Progress—Components of the Prescription Guide were tested with approximately 40 people with neuromotor involvement severe enough to impair or abolish functional speech, as well as over 50 able-bodied subjects.

Preliminary Results—Preliminary results from comparison of predictions and measures of communicative function with 11 experienced communication-device users support the predictive validity both of the rate prediction and the Benefit score.

The subsequently revised system, in its December 1986 version, has been applied with eight patients. These and additional patients will be followed up in

order to acquire actual performance data for comparison with system predictions.

Future Plans/Implications—Plans are being carried out to implement the system in clinical settings in this country and abroad to provide further testing of clinical feasibility and improve client service in these settings. Options for commercialization of the system are being investigated.

Publications Resulting from This Research

A Needs-Features Spreadsheet for Communication Device Prescription. Goodenough-Trepagnier C, Rosen MJ, Minneman S, Allen C, Chen K, Felts T, Chung G, *Proceedings of the 8th Annual RESNA Conference*, 332-334, Memphis, TN, 1985.

Assessment of Need and Prediction of Benefit in Prescription of Communication Devices for the Nonvocal. Goodenough-Trepagnier C, Rosen MJ, *Proceedings of 8th Annual Conference of the Engineering in Medicine and Biology Society of the IEEE*, 1876-1879, 1986.

Preliminary Validation of Prescription Guide for Selection of Communication Aids. Goodenough-Trepagnier C, Rosen MJ, Jandura L, Getschow C, Genoese-Zerbi F, Felts T, Minneman S, *Proceedings of the 10th Annual RESNA Conference*, 100-102, San Jose, CA, June 1987.

Quantification of Device Evaluation. Rosen MJ, Goodenough-Trepagnier C, Felts T, Genoese-Zerbi F, *Proceedings of the 10th Annual RESNA Conference*, 180-182, San Jose, CA, June 1987.

Predictive Value of an Augmentative Communication Prescription Guide. Goodenough-Trepagnier C, Rosen MJ, presented at the American Academy for Cerebral Palsy & Developmental Medicine, 1987.

Early Intervention with Globally Aphasic Stroke Patients Using a Computerized Visual Communication Technique

Cheryl Goodenough-Trepagnier, Ph.D.; Errol Baker, Ph.D.; Michael P. Alexander, M.D.
New England Medical Center Hospital, Boston, MA 02111

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—This project undertakes the controlled testing of a computerized visual communication system as an early intervention therapy for people with severe global aphasia resulting from cerebrovascular accident. The methodology is a large-sample, controlled, longitudinal group study. Patients will be enrolled within two weeks of their stroke, and the experimental and control therapies offered daily for a month. Patients will be re-assessed at intervals to assess the short and long-term effects of participation in the experimental therapy, and to identify predictors of recovery of language function.

The project began on September 1, 1987.

Progress—Use of the computerized visual communication system has proven helpful to functional communication and to recovery of language function in some cases, despite the fact that exposure to the technique was provided after recovery had appeared to have halted. The new project will provide the first test of the efficacy of this approach when offered at the time the recovery curve is steepest, within the first few weeks after the stroke.

Stroke Clinical Center Grant: Remediation of Left-Sided Neglect

Laurence M. Binder and Lee Ann Golper
Oregon Health Sciences University, Portland, OR 97201

Sponsor: *National Institutes of Health*

Purpose—This Stroke Clinical Center Grant is a new application representing a continuation and extension of investigations initiated by the Comprehensive Stroke Center Contract, National Institute of Neurological and Communicative Disorders and Stroke (NINCDS), Contract No. N01-NS-8-2387, June 1978 – June 1981. The major thrust of this contract is to assess the community (the State of Oregon in our case) profile of strokes, primarily demographic in nature; this contract mobilized a broad interest in our stroke patient, which represents the centerpiece of this grant application. Our investigations emphasize therapies focused upon stroke patients in three broad areas of importance in the continuum of the problem: 1) preventive therapy; 2) acute medical treatments; and, 3) rehabilitation intervention for higher cortical impairment.

1) Preventive therapies are designed to assess

various risk and prognostic factors in stroke patients to develop better molecular handles on both acute therapy and prevention. Factors which may yield to better identification and therapy of risks are: mononuclear cell cholesterol ester hydrolase activity; glycosylated hemoglobin; cholesterol turnover in atheromatous plaques; and, physiochemical bases for platelet behavior in stroke.

2) Acute medical treatments focus initially upon the potentially beneficial assessment of prostacyclin infusion. In addition, staged, sequential evaluation of aminophylline/barbiturate and vasopressors will be continued in a prospective, randomized fashion.

3) Rehabilitative intervention for higher cortical impairment deals with neuropsychological and language impairments with compensatory learning strategies.

Treatment of Affective Deficits in Stroke Rehabilitation

Wayne A. Gordon
Mount Sinai School of Medicine, New York, NY 10029

Sponsor: *National Institutes of Health*

Purpose—Post-stroke affective disturbances are pervasive, i.e., they affect anywhere from 40-65 percent of stroke patients. The diagnosis and treatment of these disturbances in stroke patients is a major untreated problem facing the medical rehabilitation community. Traditional approaches to diagnosis that have relied exclusively on verbal self-report or nonverbal expressions of depression have not adequately addressed either the communication difficulties of aphasics or some of the other cognitive disturbances, i.e., aprosodia, minimization, and concrete thinking, which limit the cognitive capacities of stroke patients. Furthermore, the effectiveness

of various approaches to treatment has not been systematically studied in this population.

The aims of this proposed study are twofold: first, to validate a comprehensive diagnostic battery which permits an accurate examination of the affective disorders following stroke; and secondly, to evaluate the effectiveness of two approaches to treatment (anti-depressants and cognitive therapy) when administered singly or in combination. It is expected that greater accuracy in diagnosis and more aggressive treatment will significantly improve the quality of life of this subgroup of older Americans.

Rehabilitative Software for Head Trauma Victims

Sandra E. Hutchins

Emerson & Stern Associates, San Diego, CA 92121

Sponsor: National Institutes of Health

Purpose—The goal of this effort is the development of an effective software package tailored to the needs of brain-injured patients relearning independent living skills; it will be designed to serve as a bridge between intensive therapeutic intervention and home-based support networks. The specific aims of Phase II include improvement and expansion of the existing software and a controlled study of its efficacy.

A team of healthcare professionals, educators, and computer specialists has been assembled for this 2-year undertaking. Approximately 10 months will be spent on software improvement and expansion, coupled with informal software evaluation by a panel of head-injured patients. The concluding 14 months will be devoted to a controlled study meas-

uring patients' neuropsychological, psychosocial, and academic status pre- and post-treatment. There will be 20 patients each in the control and experimental groups.

Technological innovations include: 1) provisions for parents/therapists to personalize the software to the individual patient's environment and abilities; 2) extensive record keeping in the software to track patient progress; and, 3) a variety of user interactive mechanisms tailored to the needs of patients with cognitive and/or motor impairments. No such software currently exists.

One of the outgrowths of this project will be a software authoring system suitable for creating programs for multiple rehabilitative and special education settings.

Subthreshold Memory Phenomena

Thomas O. Nelson

University of Washington, Department of Psychology, Seattle, WA 98195

Sponsor: National Institutes of Health

Purpose—The primary subthreshold-memory paradigm to be used during the proposed grant period is the feeling of knowing, although other subthreshold-memory paradigms also will be employed (e.g., relearning). The feeling of knowing refers to a person's predictions about subsequent memory performance on items that are below the threshold of a particular performance test (e.g., predicting subsequent recognition performance on nonrecalled items).

The proposed experiments are grouped into six conceptual themes. One overall goal of these themes is the development of an empirically sound theory of the feeling of knowing that will answer the

questions "What is the feeling of knowing based upon?" and "What is the predictive accuracy of the feeling of knowing?" Besides providing a theoretical understanding of the feeling of knowing and its role in the cognitive system, answers to these questions will help improve both the accuracy of the feeling of knowing and other cognitive processing that is mediated by the feeling of knowing (e.g., the allocation of study time during relearning). Such improvements have potentially important ramifications for mental health situations, including improved diagnosis of memory disorders and more efficient rehabilitation of victims of stroke and amnesia.

Precursors of Stroke Incidence and Prognosis

Philip A. Wolf

Boston University School of Medicine, Boston, MA 02118

Sponsor: National Institutes of Health

Purpose—It is proposed to extend the prospective findings of the Framingham Study on stroke to 30 years of follow-up, including the age groups 75-84 years, and to examine a number of possible precursors for which there has been too little follow-up. These include the role of: arrhythmias as determined by one hour ECG monitoring; echocardiographic findings of valvular and myocardial dysfunction; lipid profiles including LDL and HDL cholesterol; physical activity status; menopausal status; psychosocial factors including Type A personality; carotid bruit; Ecolyzer confirmed smoking histories; and, glucose tolerance based on a glucose load.

Further studies of asymptomatic carotid bruits will be carried out by analyzing the continuous wave Doppler signal for its direction, mean frequency, and frequency content, as they are found at selected moments in the cardiac cycle, over the carotid arteries in the neck, and phonoangiography of carotid bruit in an attempt to identify those bruits which are true precursors of stroke. A more accurate delineation of the type of stroke will be accomplished using CT scan information in addition to clinical

findings. This should permit better definition of the frequency of different types of stroke and a more accurate determination of the epidemiologic features of each type. The stroke, its precursors and disability will be pursued focusing particularly in the elderly. Functional assessment of the patients' daily activities will be made at the time of stroke, and 3, 6, and 12 months later. Scores on recently standardized tests scales of activities of daily living (feeding, dressing, grooming, bathing, etc); assessments of function in the home and in society; and, the use of aids and appliances following stroke will be obtained by a rehabilitation nurse.

These data will permit detailed evaluation of disability following stroke in a general population sample. An attempt will be made to devise a more powerful predictive stroke risk profile using those ingredients identified above as independent contributors to stroke incidence. The decline in mortality rates from stroke has accelerated in recent years. Secular trends in incidence by stroke type will require more cases occurring over time and should be available as a byproduct of this proposal.

Sensorimotor Interactions in Motor Unit Control

Yukio Noda, M.D., and Carlo J. De Luca, Ph.D.

NeuroMuscular Research Center, Boston University, Boston, MA 02215

Sponsor: NeuroMuscular Research Center

Purpose—This study is a continuation of previous work done at the Center investigating the modulatory effect of sensory input from the skin on motor control (cf. description of study entitled "Long-Term Effects of Topical Anesthesia in Stroke Patients: Measurement and Analysis of Neurophysiological Reflexes.") In the earlier studies, a topical anesthetic coupled with physical therapy was applied to the rigid and spastic muscles of patients with brain or spinal cord lesions. This procedure produced an increased range of movement in vital joints, in addition to revealing that the application of topical anesthetics changes the amplitude of the

H-reflex. The purpose of the present study is to clarify some aspects of the relationship between sensory input from the skin and motor output.

Progress—Myoelectric signals were detected for the First Dorsal Interosseous muscles while the subject generated an isometric contraction up to the 50 percent MVC level. Thereafter, the signals were decomposed into their constituent motor unit action potential trains. The recruitment force thresholds of the progressively recruited motor units were determined before and after the application of topical anesthetics.

Results—Initial results indicate that the recruitment force threshold levels of motor units recruited below 10 percent MVC level increase, while those of motor units recruited above 20 percent MVC decrease, due to skin desensitization. These effects are noted up to 45 minutes post-anesthetic application. It is suggested that the sensory input from the skin has

an excitatory effect on the small slow-twitch motor unit and an inhibitory effect on the large fast-twitch motor unit. Currently, we are further analyzing the data to substantiate the initial observations.

The results of this study were presented at the 16th Annual Meeting of the Society for Neuroscience, November 1986, in Washington, D.C.

Medication Effects on Attention and Arousal

John Whyte, M.D., Ph.D.; Julia Reger, B.A.; Mel Glenn, M.D.; Bruno Wroblewski, M.S.; William Singer, M.D.
Greenery Rehabilitation and Skilled Nursing Center, Boston, MA 02135

Sponsor: *Tufts New England Medical Center and National Institute on Disability and Rehabilitation Research*

Purpose—Traumatic brain injury frequently results in deficits in arousal and attention. These deficits contribute to slowed progress in rehabilitation therapy and to impaired function in the naturalistic environment. The purpose of this research is to develop an assessment protocol for measuring the various components of the arousal/attention system, to validate these testing protocols, and to use them to measure the positive and negative effects of various medications on arousal and attention.

Progress—The first year of the project has been devoted to tool development. Five computer testing protocols have been written to assess different components of arousal and attention. These include critical flicker fusion to measure tonic arousal, a warned versus unwarned reaction time task to measure phasic arousal, a prolonged stimulus detection task to measure sustained attention, a distractor versus nondistractor reaction time task to measure distractibility, and a choice reaction time task to measure information processing speed. These tasks are now being piloted with normals and then with head-injured adults.

In addition to performing laboratory tasks, patients will participate in "research therapy" on and off medication with video-taped behavioral sampling. Tasks similar to those patients commonly engage in in therapy are being developed with alternate forms of equivalent difficulty. Eight block

designs have been developed and shown to be equal in difficulty, as measured by speed of completion.

Twenty short news stories were recorded on tape at standard speed. Auditory comprehension quizzes (to assess attentional lapses during listening) were developed for each. Sixteen of the 20 stories proved to be of comparable difficulty and will be suitable for use in the formal research. Eight prevocational sorting tasks are currently under development. Other tasks requiring no piloting have also been selected.

Preliminary Results—During the pilot phase the goals are: 1) to insure that each of the tasks is "doable" on its own; 2) that alternate forms of the task are of equivalent difficulty so that later changes in performance can be attributed to medication effects rather than task differences; and, 3) that each of the tasks demonstrates sensitivity to the variable (s) of interest. The first two of these have been demonstrated and the third is in progress.

Future Plans/Implications—Piloting will continue by demonstrating that normal subjects respond as predicted to the warnings, information loads, and distractions being tested. Next, head-injured subjects undergoing no medication changes will be tested to determine the stability (test-retest reliability) of performance scores in the absence of changes. Finally, medication testing will begin.

XIV. Geriatrics

Age-Related Changes in Sensorimotor Performance

Barbara M. Myklebust, Ph.D.

Laboratory of Sensory-Motor Performance, Veterans Administration Medical Center, Milwaukee, WI 53295

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The goal of the proposed research is to achieve an integrated understanding of changes in sensory-motor performance as healthy people grow older. The broadest statement of the question to be answered is “What are the age-related changes in the components of the sensory and motor systems, and how do they relate to functional changes with age?” Answers to this question will help us understand sensorimotor deficits in older patients with neurologic disease.

Progress—We are evaluating a population of 160 individuals, ranging from 45 to 84 years, utilizing measures which objectively evaluate segments of the neuromusculoskeletal system (myostatic reflexes; joint compliance; muscle strength; simple ankle joint voluntary movements; somatosensory evoked potentials) and methods which identify systemic functional integrity (postural stability and steadiness; gait). Correlations are being made of the study variables for each of these test procedures to test the hypotheses about changes in sensory-motor performance in older subjects. Special attention is being paid to variations in data from subjects who report a history of falling or who have a sense of “unsteadiness.” Because of the integrated nature of the tests which we perform, patients with neurologic disease have also been referred for study by the Departments of Neurology, Neurosurgery, Physical Medicine and Rehabilitation, and Pediatric Neurology and Orthopedics.

In addition to a questionnaire and general medical history and a general physical and neurological examination, all subjects studied are being evaluated by the following tests: Functional tests: objective tests of muscle strength; gait study; test of postural stability and steadiness (standing balance); Motor coordination studies of the lower limbs: myostatic reflex test; ankle joint compliance; voluntary ankle joint movement; Sensory test: somatosensory evoked

potentials. Muscle strength is compared in normal adult subjects using the modified Cybex isokinetic dynamometer and the newly acquired Penney and Giles myometer. We intend to validate the use of the myometer to simplify data collection on the healthy elderly subjects. Output of strength from the myometer can then be directly downloaded to a microcomputer for automatic data collection and analysis.

Gait studies are performed on videotape, data is digitized, and analyzed on a microcomputer. The Motion Analysis system captures data optically through a charge-coupled device camera. Two-dimensional data is analyzed on an IBM-AT computer using Expert Vision System software. We measure hip, knee, and ankle joint angles, and velocity and distance profiles for each trial, as well as statistical analysis of these parameters. We are using new software to create stick figures to illustrate movement of the trunk and limb segments during the gait cycle. Video recording permits immediate feedback for the subject, researcher, and clinician. Slow-motion playback of a subject's gait allows improved accuracy of observational analysis, against which the objective computer analysis is compared. This new digitized analysis increases the consistency of measurements between subjects while maintaining the accuracy of the photographic method.

Preliminary Results—During the first 6 months of this project, we have upgraded the data acquisition and data analysis systems for the functional performance and motor control methods. We have been accumulating a database of sensorimotor performance measures on young adult normal volunteers to verify the continuity of new data acquisition systems with the previous methods, and to serve as controls for the formal study of healthy elderly subjects. Furthermore, serial and longitudinal data have been collected from patients with such neurologic dis-

eases as spinal cord injury, cervical spondylotic myelopathy, multiple sclerosis, stroke, developmental delay, Alzheimer's disease, and pyramidal and extrapyramidal disorders.

Future Plans/Implications—Postural stability and steadiness in standing will continue to be evaluated by monitoring the center of pressure (i.e., the excursion of the vertical projection of the center of gravity) and the force distribution under each foot. Data will be collected using a microprocessor-based system (SDK-85) with 12-bit A/D converter to obtain the data from the strain gauge elements in the force plates. The distribution of forces under the left and

right feet and the corresponding weights will be computed and stored. As an option, the overall center of pressure can be output through D/A converters to an oscilloscope for visual feedback to the tester or the subject. Subsequent to data collection, the stored values as a function of time will be downloaded to the IBM-AT for correlation with EMG data and further analysis.

In the interim, tests of the myostatic reflex have been conducted using a portable microcomputer based data collection system, and some limited motor control studies have been conducted in collaboration with the Motor Control Laboratory of Rush Medical Center.

Efficacy of Injectable Collagen to Correct Glottal Insufficiency

Charles N. Ford, M.D.

William S. Middleton Memorial Veterans Administration Hospital, Madison, WI 53705

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This study is a pilot project to determine the efficacy of injectable collagen in improving the voices of elderly patients suffering from presbylaryngis—a term used to describe laryngeal changes in the elderly. With advanced age, the voice often becomes weak and breathy due to atrophy of the vocal fold parenchyma. Although such changes are physiologic events associated with aging, these changes may result in impaired ability to communicate and to function in a competitive environment.

Observations in elderly patients treated for glottic insufficiency due to neurologically-induced atrophy indicated that injection of collagen to augment the atrophic vocal fold could increase vocal efficiency. Elderly subjects without associated deficits, as well as those with paresis or paralysis of the laryngeal musculature, would seem to be candidates for such therapy. This study was designed to see if such an approach might be helpful in the patient with presbylaryngis.

Progress—It was estimated that 20 patients with presbylaryngis might be treated over a 1-year period. As of this date, we have screened 36 patients, 18 of whom appear to meet the clinical criteria for presbylaryngis. Progress to date may be summarized as follows:

Thirty-six patients have been screened. Of these,

6 had normal larynges (no pathology); 2, gastroesophageal reflux laryngitis; 2, pulmonary disease; 2, neurological disease; 2, laryngeal cancer; 3, spasmodic dysphonia; and 18, presbylaryngis. Of the presbylaryngis group, 12 had completed voice studies with data processed. Nine underwent skin tests for collagen sensitivity that might preclude collagen injections. All nine patients had nonreactive results. Two patients have completed injection treatment and appropriate follow-up studies. Four patients are scheduled for injection treatment and three are still to be scheduled.

Preliminary Results—Of the two patients treated, there have been no adverse reactions, and the patients feel that their voices have improved. Data analysis of aerodynamic and acoustic studies show areas of improvement, but the two patients are dissimilar anatomically, so it is not meaningful to analyze their pooled or averaged data. In both patients, videostroboscopic studies revealed improved function with more complete vocal fold approximation during phonation following treatment. Both patients exhibited significantly improved habitual intensity or loudness during phonation following injection. All parameters appeared to be improved in one patient with atrophic presbylaryngis changes associated with paresis; changes were mixed

in the other patient who had more subtle changes without paresis. This might suggest that we can anticipate the greatest improvement in patients with the most incapacitated larynges.

Future Plans/Implications—Based on this preliminary study, we have designed a more comprehensive study which will entail a multi-faceted approach to the rehabilitation of patients with symptomatic presbylaryngis. It was apparent that many of the patients who presented had associated problems that con-

tributed to their disability. With some disorders, e.g., early cancer of the vocal fold, this required immediate surgical management. In other patients, the pathology and symptoms were not sufficient to warrant the risk of possible failure of an experimental injection procedure. Some of these patients have been responsive to behavior modification and medical management. Future studies will explore the roles of voice therapy, and medical and surgical management of patients with presbylaryngis.

Geriatric Prosthetics: Design and Development of an Improved Above-Knee Socket (Project Extension)

Hans R. Lehneis, Ph.D.; Gustav Rubin, M.D.; Vern L. Houston, Ph.D.
Veterans Administration Medical Center, New York, NY 10010

Sponsor: VA Rehabilitation Research and Development Service (Project #XA308-2RA)

Purpose—The long-term objective of this project is to develop a prosthesis for geriatric Above-Knee (AK) amputees that is comfortable, stable, and energy efficient, and that meets all of the special physiological, biomechanical, and psychological needs of these patients. The immediate objective of this project is to develop the socket component of this prosthesis, such that: 1) it does not introduce stresses in the stump tissues that impair circulation or exceed the viscoelastic limits of these tissues; 2) it is comfortable when sitting, standing, and walking; 3) it provides maximum stability when standing and walking; and, 4) it requires minimal strength to don, to doff, and to use.

The following research plan is proposed:

a) Continue present project protocol of measurement of physiological, biomechanical and prosthetics parameters of geriatric AK amputees and control subjects to identify the special prosthetics needs and characteristics of geriatric amputees.

b) Continue present project protocol of fitting experimental sockets derived using uniform force/tissue displacement (UF/TD) measurements to expand empirical database of socket and stump contours, loading patterns, physiological, biomechanical, and prosthetics parameters.

c) Investigate new socket materials and fabrication

techniques permitting incorporation of controlled gradients in socket wall stiffness, especially at the socket brim, to reduce stump tissue stress concentrations, reduce circulation impairment, and increase patient comfort.

d) Evaluate the effects of socket designs on stump circulation using ultrasonic doppler femoral artery and vein flow measurements, and laser doppler skin capillary perfusion measurements.

e) Conduct comparative static and dynamic socket/stump normal and shear stress loading studies by instrumenting quadrilateral, (UF/TD), and finite element analysis (FEA) sockets for four subjects. Use socket/stump loading study results to iteratively formulate socket design improvements.

f) Continue present project work on developing methods of characterizing and measuring the viscoelastic properties of stump tissues. Develop discrete element models of cutaneous and subcutaneous stump tissues as nonhomogeneous, nonlinear, anisotropic, hydrated, composite biomaterials. Develop computer software incorporating stump tissue models in conjunction with finite element analysis to estimate optimum socket/stump load distribution and the corresponding stump (socket) shape.

g) Develop new, more comfortable, stable, and energy efficient prosthesis suspension systems.

Electromyographic Incontinence Alert Device

Pat D. O'Donnell, M.D.

Veterans Administration Medical Center, Little Rock, AR 72206

Sponsor: VA Rehabilitation Research and Development Service (Project #B376-DA)

Purpose—The objective of this proposal is to develop an electronic device that measures the decline in electromyographic activity of the pelvic floor muscles and produces an alert to the patient of an impending bladder contraction and subsequent loss of urine. The early warning provided to the patient by the unit will be used as biofeedback to teach the patient to control continence in a cost-effective method with readily available maintenance therapy.

Urinary incontinence is one of the major social and economic problems affecting the elderly population in our country. Incontinence in the aged is the second major cause of admissions to long-term care facilities producing a total annual cost of more than eight billion dollars. Medical and surgical management of urinary incontinence in this group of patients has had limited success and a strong research effort at this time is being focused on behavioral therapy of incontinence. Treatment modalities such as biofeedback have proved to be successful interventions but have the problem of the cost of administering therapy and long-term failures due to lack of maintenance therapy.

Urodynamic evaluation of bladder function in the aged incontinent patient shows most patients to have involuntary detrusor contractions associated with urinary incontinence. The onset of an involuntary detrusor contraction is preceded by a sharp fall in electromyographic activity of the pelvic floor muscles that occurs 6 to 8 seconds before the rise in detrusor pressure is detected. Using the principle that the fall in electromyogram (EMG) activity precedes the involuntary detrusor contraction, the purpose of this project is to design, build, and evaluate an electronic device that will detect the fall in EMG activity and alert the patient of an impending detrusor contraction. This early warning system will provide the patient with a training device that will assist in preventing urinary incontinence as well as teach the patient the skills required to control urinary continence. The device can be worn by the patient and will serve as a biofeedback training and reinforcement unit that is inexpensive to administer and can be used intermittently over a long period of time.

Non-Auditory Factors Affecting Hearing Aid Use in Elderly Veterans

Bruce Z. Rappaport, Ph.D., and Stephen A. Fausti, Ph.D.

Auditory Research Laboratory, Veterans Administration Medical Center, Portland, OR 97207

Sponsor: VA Rehabilitation Research and Development Service (Pilot Project #C952-PA)

Purpose—This pilot project will examine the non-auditory factors that influence successful use of hearing aids in elderly veterans. These factors include cognitive status, fine motor coordination, family support, and visual acuity. They are frequently mentioned in the literature when considering amplification for the hearing-impaired elderly. However, the influence of these different components has not been systematically evaluated in an effort to predict outcome with hearing aids.

The short-term goal of this study will be to review, isolate, and assess non-auditory factors that can be measured in a systematic way. A secondary goal would be to evaluate the utility of the Hearing

Handicap Inventory for the Elderly (HHIE) (Ventry and Weinstein, 1982) with elderly hearing-impaired veterans. At the culmination of the pilot study, it is anticipated that a proposal will be submitted for a multi-year grant to study the non-auditory factors that have a significant relationship with successful hearing aid use in elderly veterans. Selected factors would be analyzed (multiple linear regression) to determine how each influences hearing aid use and how they interact with one another. Further study might be aimed at evaluating whether those factors that prove to be poor predictors can be improved or circumvented to increase the likelihood of success with amplification.

Integrated System for the Management of Wandering Behavior in the Memory-Impaired Elderly: An Interagency Report

Doris J. Rouse, Ph.D.; Janet D. Griffith, Ph.D.; Lawrence H. Trachtman, M.S.; Daniel L. Winfield, M.S.
Research Triangle Institute, Center for Technology Applications, Research Triangle Park, NC 27709

Sponsors: VA Rehabilitation and Research Development Service; Administration on Aging; National Aeronautics and Space Administration; National Institute on Aging; National Institute on Disability and Rehabilitation Research

Purpose—The purpose of this effort is to develop a notification and locator system to aid caregivers in the management of wandering behavior as exhibited by the clinically diagnosed mild to moderately cognitively-impaired elderly. This includes those persons suffering from dementia of the Alzheimer's type as well as other dementias.

Wandering has both beneficial and detrimental effects on persons who wander, and on their caregivers. The freedom to wander safely may help maintain the memory-impaired person's physical, psychological, and activities of daily living capabilities, as well as provide for activities that are intrinsically enjoyable (e.g., visual stimulation, exercise, and social interaction). Yet, wandering can expose the person to physical danger and even death. The need for virtually constant surveillance is particularly devastating in the home where one or only a few caregivers have the responsibility for providing this surveillance. Caregivers respond to these problems by restricting a person's freedom of movement and, in some cases, institutionalizing the individual. Both family and professional caregivers are affected by their fear for the person's safety and their feeling of responsibility to provide for that safety.

Current techniques and devices provide less than adequate solutions to the problem of wandering. Particularly for the home setting, current devices tend to be either overly restrictive or provide inadequate security. The objective of this effort is to develop, produce, and market a device based on NASA and other technology which meets the needs of both the wanderer and the caregiver.

Progress—A Phase Zero Needs Assessment and Feasibility Study funded by the five sponsoring agencies has been completed. This study suggests the development of a modular system capable of using different components based on the requirements of the older person, the caregiver, and the environment. A proposed feature of the system is

that it not only monitor doorways, as most current products do, but that it also allow the older person freedom of movement within a safe perimeter, e.g., an outside yard. In addition, the system could notify not only the caregiver, but the wanderer as well.

Supervision of the developmental work is being provided by technical experts at NASA's Johnson Space Center in the areas of radio frequency (RF) communications, frequency spectrum allocation, ergonomics, antenna design, tracking techniques, systems engineering, mechanical design, and component miniaturization. In addition, access to NASA environmental and RF test facilities and computer modeling systems can be provided.

A Request for Proposals (RFP) was issued in May, 1987, by NASA to select a collaborating manufacturer for device development. An award was made in November, 1987, to provide the design and trade-off specifications. This phase of the effort will be completed in 6 months.

Future Plans/Implications—The contractual effort to develop the notification and locator system will be conducted in two phases with incremental co-funding provided by the five sponsoring agencies. It is anticipated that the total project will be completed within a two-year time frame. In addition to Phase I, Engineering Design, expected to be completed in approximately six months, Phase II, Prototype Development, will take approximately sixteen months. A clinical evaluation will follow. The decision by the sponsoring agencies to continue on to each successive phase will depend largely upon the results of the prior phase.

The project representatives of the sponsoring agencies are: Administration on Aging, Anita Shalit; National Aeronautics and Space Administration, Raymond P. Whitten; National Institute on Aging, Shirley Bagley; National Institute on Disability and Rehabilitation Research, Joseph Traub; VA Rehabilitation Research and Development Service, Dr. Margaret J. Giannini.

Work Disability, Disability Management, and the Older Worker

Kenneth Mitchell, Ph.D., and Bobbi May-Gross

The International Center for Industry, Labor, and Rehabilitation, Dublin, OH 43017

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The purpose of the project is to analyze critically the employer and medical and personal influences on the work status of the older worker.

Progress—A variety of large employers in the areas of manufacturing, healthcare, city municipalities, and transportation were asked to participate in the research program. A corporate analysis was developed that documents the employer's response to disability, and the key factors that impact on the benefits and worker's compensation costs.

Employees within the selected companies over the age of 45 as of December 31, 1984, were invited to participate in the research by completing a health and vocational questionnaire. Of these employees, those who had had a major health problem resulting in lost time from work were asked to complete additional sections focusing on their disability experience and rehabilitation intervention. The final target of analysis involved identifying and defining the healthcare services/providers within the local community.

Preliminary Results—Labor relations is a very critical issue with respect to a company's ability to participate in the project. Union attitudes and perceptions heavily influence the participation rate of the employees. In addition, the labor relations climate within a company is a strong precursor to the scope and nature of disability problems of the older workers.

Employers feel that participation in the research may increase expectations of the older workforce in that the employees will anticipate changes in their current work status, retirement programs and disability benefits. Employers also believe that workers may feel threatened if they think the research is being conducted for other reasons, i.e., to "weed out" the older or undesirable employees and/or older employees who have had health problems.

Employers have established good controls and consistent claims monitoring on worker's compensation cases; however, they do not have a comparable strategy in place for non-work-related injuries/

illnesses. The management of those cases is relinquished to the insurance company, which provides little or no expertise in the disability management of the claim. Back problems, degenerative arthritis, carpal tunnel syndrome, and gynecological conditions comprise the majority of lost time disabilities for the older workers within the companies reviewed.

Employers do not evaluate rehabilitation providers. There is no written policy and/or other method in place for employers to appropriately assess the services being provided to their older workers, and workforce in general. The employer assumes this is being handled by the service company/actuary.

No formal linkages exist between employers and healthcare providers. Employees tend to seek medical attention where it is most convenient for them; employers hesitate to recommend or encourage the employee to utilize one type of healthcare provider and/or service over another.

Future Plans/Implications—The analysis of this data will be helpful in identifying variables that are a critical influence on older workers in the disability process. Once these variables are known, the impact of disability and chronic illness can be better controlled, resulting both in reduced healthcare costs and protection for the employability of the older worker.

The International Center will continue to conduct research in the area of the older worker, as well as participate in training and education programs that deal with the issues of an aging workforce. Currently, the International Center is planning a National Conference on Work Disability, Disability Management and the Older Worker, which will be a forum for corporate managers and labor officials, healthcare professionals/administrators, and public policy makers, as well as for researchers and specialists in the aforementioned areas. The conference will include a coordinated series of lectures and position papers presented from noted professionals dealing with issues related to older workers. This is scheduled to take place in the spring of 1988.

Perceptual Retention and Age

D. Arenberg

National Institute on Aging, National Institutes of Health, Bethesda, MD 20892

Sponsor: *National Institutes of Health*

Purpose—Among the goals of this project is to describe adult age differences and age changes in nonverbal memory performance. Nonverbal memory is measured in the Baltimore Longitudinal Study of Aging (BSLA) with the Benton Visual Retention Test (BVRT).

Progress—Previous analyses of 6-year and 12-year longitudinal data indicated that for men, performance on the BVRT declines late in life. This year, extensive analyses of individual regression measures of change found substantial mean declines in the groups of men who were in their sixties or seventies when first tested. The correlation of age with change

was $-.38$. These regression measures of change were based on 12 years (3 points) or 18 years (4 points) of longitudinal data.

Also this year, the BVRT was one of the measures included in a comparison of noninsulin dependent diabetic men with healthy age-matched men. There is some controversy in the literature about the effects of diabetes on cognitive performance; all of those studies were cross-sectional. No differences were found in the cross-sectional analysis or the longitudinal comparisons of change in BVRT performance in the BLSA. No support was found for the hypothesis that diabetes accelerates age declines in cognitive performance.

Geriatric Medicine Academic Award

Paul Beck

University of North Carolina School of Medicine, Chapel Hill, NC 27514

Sponsor: *National Institutes of Health*

Purpose—The long-term objective of this Geriatric Medicine Academic Award application is to develop a superior curriculum in aging and geriatric medicine at the University of North Carolina, Chapel Hill, (UNC-CH) School of Medicine that will stimulate medical students, house officers, faculty, and practicing physicians to provide high quality medical care of the elderly and which will attract outstanding students and house officers to research in the processes of aging and diseases of the elderly.

The specific aims and methods of this curriculum proposal are: 1) to update the standard required curriculum for medical students to insure that they obtain the knowledge of gerontology and skills of communication and physical examination necessary for working with elderly patients; 2) to reinforce the principles of gerontology and geriatric care through clinical problem solving experiences with case ex-

ercises and with geriatric patients. Resident's reports, case conferences, medical grand rounds, and interdisciplinary (medical, nursing, social work, occupational therapy) team consultations will be used as teaching settings; 3) to develop model care sites (at the University teaching hospital, Area Health Education Centers (AHEC's), retirement communities, nursing homes) where geriatric care will be provided in a manner which is conducive to learning; 4) to enhance the competence of the faculty in dealing with the problems of aging, particularly encouraging acquisition of knowledge about geriatric topics that are related to their respective areas of expertise; and, 5) to foster research opportunities for students and faculty which will bring about new solutions for common problems of the elderly and/or better ways of coping with them.

Studies in Idiopathic Normal Pressure Hydrocephalus

Peter M. Black

Massachusetts General Hospital, Ambulatory Care Center, Boston, MA 02114

Sponsor: *National Institutes of Health*

Purpose—Idiopathic Normal Pressure Hydrocephalus (INPH) is an important cause of dementia, gait disturbance, and incontinence in the elderly. It may be confused with Alzheimer's Disease (AD); unlike AD, however, it may be markedly improved by cerebrospinal fluid (CSF) shunting. Because CSF shunting may have substantial morbidity, it is important to select patients carefully. There are presently no reliable criteria for deciding to shunt. This proposal has two goals: to clarify the diagnostic differences between INPH and AD, and to evaluate three tests presently thought to predict a good shunt response in INPH.

The study will test three measures presently thought to distinguish INPH from AD: concentrations of the peptides vasopressin and somatostatin in CSF, atrophy and periventricular lucency on computed tomographic and magnetic resonance im-

aging, and gait and psychometric test profile. These features will be compared in 50 patients given the diagnosis of INPH over a three year period with 50 others given the diagnosis of AD. To help establish predictive tests for INPH, the study will use the tests just described as well as overnight recording of CSF pressure, lumbo-ventricular perfusion of CSF, and withdrawal of 50 cc of CSF with subsequent analysis of gait. Domain analysis as well as analysis of variance will be used in the statistical evaluation of these measures.

This study will provide the first prospective and rigorous testing of several criteria thought to distinguish INPH from AD and predict a good shunt response. By refining criteria for diagnosis and shunt placement it will be a major contribution to the management of gait and memory disorder in the elderly.

Respite Care for Older Adults: A Prototype

Joan L. Brogdon

Kin Care, Inc., Chicago, IL 60614

Sponsor: *National Institutes of Health*

Purpose—This research is to implement, further refine and evaluate a prototype within the private business sector which uses a foster care model to provide short-term, overnight care to frail older adults using private residences. Appropriate community care utilization can ease caregiver burden and stress and decrease the likelihood of institutional placement. One undeveloped service option is short-term, overnight, community-based respite care within private residences.

The anticipated outcome will be an effective, self-sustaining, marketable service which can be replicated by either proprietary or not-for-profit agencies for frail older adults or other dependent populations. Data are expected to support the ability of private individuals to implement a training program generalized from behavioral approaches and nursing care

concepts enabling them to function as surrogate caregivers. Caregiver burden and stress is expected to be relieved. Frail older adults who utilize the service are expected to maintain their living statuses longer than would be expected by chance. Financial data are expected to support Kin Care's ability to function independently in the third year and licensure recommendations will be developed. A pre/post test design with follow-up utilizing a non-equivalent comparison group and survey techniques will be implemented. Eighty older adults and 40 caregivers will comprise the main sample and be followed over a period of one year. Data analysis will utilize descriptive and inferential statistics including Anova, Manova, Logit and Probit procedures.

Epidemiology of Cardiovascular Diseases in the Elderly

Trudy L. Bush

Johns Hopkins University, Baltimore, MD 21205

Sponsor: National Institutes of Health

Purpose—The objective of this research is to identify and describe the distribution of risk factors for cardiovascular disease (CVD) incidence and mortality in a cohort of free-living elderly persons. The identification of risk factors for CVD in older persons is important as CVD is the leading cause of death and disability in elderly Americans and because there is evidence that CVD can be prevented or delayed in this age group.

Progress—The data to be used in these analyses were collected in the Dunedin Program, a population-based geriatric health program designed to screen persons 65 years of age and older for a wide range of medical disorders. The Dunedin Program, located in Dunedin, Florida, has been in continuous operation since July 1975. Participants are screened annually, and extensive data on CVD and CVD risk factors are gathered during each visit. Information is available from questionnaires (i.e., family history, previous and present illnesses, drug use, smoking and alcohol use), physical examinations (i.e., EKGs, pulse rate, blood pressures) and laboratory measures (i.e., glucose, cholesterol, uric acid). Through 1985, 5,085 elderly men and women had been screened at least once, and 1,540 persons had participated in the program for a full 8 years. This participation represents a total of 14,783 person-years of obser-

vation with an average follow-up of 4.9 years.

The analysis will consist of three distinct phases. In the first phase, follow-up time for each participant will be computed, and changes in risk factor status will be analyzed. Descriptive information of the distribution of risk factors, and the prevalence of CVD in the entire cohort will be presented. CVD incidence and CVD mortality rates will be calculated for all participants. In the second analysis phase, incidence rates of CVD will be computed (number of events/person-years of follow-up) by category of risk factor level at baseline. The relative risk of CVD (incidence in exposed/incidence in unexposed) will be calculated for each hypothesized risk factor. The third phase will be multivariable analyses. Cox regression models will be used to determine independent and interactive effects of the identified risk factors on the incidence of and mortality from CVD in this cohort.

This study will provide information on the prevalence and risk of CVD in a large, free-living elderly population. The potential identification of factors which may both increase the risk for CVD in older persons, and be modifiable or treatable is of significant public health importance, as modification of these factors may lead to a further reduction of events/deaths in this large and growing segment of our population.

Does Improvement in Mortality Mean Better Health?

Eileen M. Crimmins

Andrus Gerontology Center, University of Southern California, Los Angeles, CA 90089

Sponsor: National Institutes of Health

Purpose—The purpose of this research is to answer the question, "Has the recent reduction in mortality among the older population been accompanied by an improvement in health, or has the mortality decline resulted in an increase in the proportion of the older population with poor health and/or disabling conditions?"

Data employed to answer this question are from

the National Health Interview Survey of the noninstitutionalized population of the U.S. from 1969 through 1984 and surveys of the institutionalized population such as the National Nursing Home Survey available from the same period.

This project differs from others in that it takes a disease-specific approach to health and will determine levels, trends, and differentials in disability

from specific diseases for the older population subdivided by age, sex, race, ethnicity, socio-economic status and place of residence. In addition, the project proposes a detailed documentation of the cause termed "senility" which preliminary analysis has

shown to be a major cause of disability among the population 85 and over. Lastly, an analysis of the changing health of succeeding cohorts will be completed.

The Community Adaptation of Mildly Retarded Persons: The Lives and Needs of Aging Mentally Retarded Persons

Robert B. Edgerton

University of California, Los Angeles, CA 90024

Sponsor: National Institutes of Health

Progress—All goals set for Year 1 have been met on schedule. Research personnel have been recruited and trained; data indexing and retrieval systems have been completed; a large core sample pool (N equals 289) of psychometrically retarded adults has been generated; based on personal history and demographic data collection with this core sample, 4 sub-samples have been selected for intensive data collection (60 Black and 60 matched White adults—principally for research on communicative competence, 33 young adults currently enrolled in independent living training programs, and 4 sub-samples. While longitudinal data collection will continue as planned, all 4 projects anticipate data

collection, analysis, and publication in Year 2.

Future Plans—Some major topics for Year 2 data analysis are: a network analysis of the personal support systems of independently living adults; a sociolinguistic comparison of competence in giving directions between mentally retarded and normal adults; a study of parental beliefs and attitudes about the socioemotional histories of their mildly retarded, adult, children; and, a comparison of mathematical skills evoked by a test instrument versus similar skills exhibited by the same persons in everyday life.

Learned Modification of Visceral Function in Man

B.T. Engel

National Institute on Aging, National Institutes of Health, Bethesda, MD 20892

Sponsor: National Institutes of Health

Purpose—This project is concerned with the application of behavioral methods and principles to clinical medicine. Subjects are patients selected from various medical clinics, or normal subjects who are

studied to evaluate potential clinical methods. The main focus of this project is on clinical problems especially relevant to middle-aged or elderly persons.

Senile Dementia: Natural History

Denis A. Evans

Brigham and Women's Hospital, Boston, MA 02115

Sponsor: National Institutes of Health

Purpose—This study is to provide an indepth assessment of a community-based sample of persons who have been previously classified as either having

senile dementia or to be high risk for having this disorder. The study includes a clinical examination plus a surveillance by contacting the subject and a

close relative or friend every nine months. Comparison will be made with unaffected persons to define risk factors and etiologic events.

This is a 5-year study of a free-living population having been identified as positive for senile dementia by a standard screening instrument. The cases and controls will have a clinical examination with valid

and quantified measurement techniques and interviews every nine months to obtain demographic, social-psychological, cognitive, medical, drug usage information and health service utilization, and other related information. Similar information will be gathered from a relative or close friend.

Geriatric Medicine Academic Award

Steven R. Gambert

New York Medical College, Department of Medicine, Valhalla, NY

Sponsor: *National Institutes of Health*

Purpose—Changes in demography mandate that health professionals be skilled in all aspects of Geriatric healthcare. Institutions of medical education must assume a leadership role in planning and providing for future needs. New York Medical College is deeply committed to the teaching, research, and clinical aspects of Geriatrics and Gerontology. Located in Westchester County, an area where the number of elderly far exceed the national average, New York Medical College has a total enrollment of 760 M.D. candidates and over 300 graduate students. In addition, its affiliated clinical programs

provide training in a variety of settings including urban New York City.

New York Medical College proposes to establish a Program in Geriatric Education comprised of Program Director and a select Geriatric Education Group, both administratively functioning out of a newly created Center on Aging and Human Development. The program will serve to improve the quality and quantity of existing curriculum in Geriatrics and to help foster additional research and careers in Geriatrics and Gerontology.

Falls in the Elderly: Causes and Reduction

Gale M. Gehlsen

Ball State University, Muncie, IN 47306

Sponsor: *National Institutes of Health*

Purpose—There appears to be a pressing need to develop therapeutic measures for elderly Americans which will preserve their physical capacities, promote optimal functional ability and reduce the incidence of falls. The following proposal has the potential of coordinating the efforts of specialists in biomechanics, physiology, orthopaedics, and rehabilitation. These specialists are capable of focusing their research on the movement patterns of elderly adults, analyzing the results of research, recommending therapy, and evaluating the therapeutic program.

During the first year the aim of this proposed study is to determine the profile of two groups of elderly adults: one with a history of falls and one

without a history of falls. The second aim will be to determine the effects of the fall related factors on gait. The third aim will be to determine the effects of an intervention rehabilitation program on the factors which most affect gait and incidence of falls as indicated by the previous two studies.

A total of 60 (30 males and 30 females) healthy caucasian volunteers will comprise this study. The subjects will be placed into two groups (i.e., history of falls and no history of falls). The following measurements will be made: anthropometer, gait, strength, flexibility, balance (static and dynamic), depth perception, and response time. The subjects will be interviewed to determine: fall assessment, medication and medical history, activity level, and

joint pain. A total of 30 subjects per factor studied will be involved in the second year project. The subjects will be elderly adults recruited from the Muncie, Indiana community. The subjects will be assigned to either a high or low score group.

The same testing procedures will be used in the second year of this study as were used in the first year. The subjects in the rehabilitation program will be a minimum of 30 and a maximum of 50 male and female subjects age 65 to 75 years with characteristics which would make them susceptible to a fall. The rehabilitation exercise program will take place

over a 10-week period, 3 days a week during the second year of study. The first year testing procedures will be repeated at the end of the rehabilitation program. The rehabilitation program will consist of activities suitable for elderly adults and will be based on the results of the first and second year investigation results and recommendations from the consulting Physician and therapist. Appropriate statistical procedures will be used to determine the significance of effect for each phase of this proposed study.

Improving Recovery from Cardiac Surgery

Catherine L. Gilliss

S/N Family Healthcare Nursing, University of California, San Francisco, CA 94143

Sponsor: *National Institutes of Health*

Progress—The Family Heart Study is a prospective randomized clinical trial of individual and family behavioral interventions of the first-time and repeat cardiac surgery patients and family members designed to: 1) monitor and enhance recovery at home; 2) reinforce inpatient teaching on risk factor reduction; and, 3) provide support to the family as primary caretaker. Family stress and coping theory and social learning theory (self-efficacy) provide the theoretical basis. Baseline (preoperative) measures of family functioning, family coping, demands of illness and cardiac status are compared with those at three and six months post-surgery, along with self-reports of recovery, self-efficacy, quality of life,

and physician appraisal of patient recovery.

Specific study aims are: 1) to test the efficacy of nursing interventions designed to facilitate posthospital recovery and rehabilitation of the cardiac surgery patient and his family; 2) to describe the impact of cardiac surgery on the family over time; and, 3) to document care needs and differences in recovery for the older (ages 70-80) cardiac surgery patient and family. Long-term objectives are to mobilize family coping and personal efficacy in recovery from surgical treatment for heart disease, in ways that maximize the surgical benefit for patients and families.

Cancer Control Science Program: Fox Chase Cancer Center: Cancer Education and Management for Patients

Wendy L. Jones

Fox Chase Cancer Center, Philadelphia, PA 19111

Sponsor: *National Institutes of Health*

Progress—The Cancer Control Science Program of the Fox Chase Cancer Center is designed to complement the existing cancer control program and basic research efforts at the center. Prior cancer control research has included hypothesis development, descriptive studies and demonstration efforts. The scope of this initiative includes primary and

secondary prevention, as well as management of the cancer patient. The ongoing research projects are: 1) Cancer Control in an Urban Neighborhood; 2) Cancer Education Program for Older Citizens; 3) Cancer Education and Management for Patients.

The primary hepatocellular carcinoma prevention studies have been continued as a developmental

study. In addition, studies are planned in the Philadelphia urban neighborhoods on lung cancer epidemiology and on dietary habits and cancer. A study using physicians' offices for smoking cessation activities is planned.

The resources and support of this CCSP program

include a core group of investigators in medical oncology, biostatistics, epidemiology, social science, health education and health planning. The shared resources for this program include the statistical laboratory, the cancer information service and education and program evaluation.

The Treatment of Acute Illness in Nursing Homes

Virgene S. Kayser-Jones

University of California, S/N Family Healthcare Nursing, San Francisco, CA 94143

Sponsor: National Institutes of Health

Purpose—The treatment of acute illness of the chronically disabled nursing home patient is a problem of great magnitude that concerns healthcare providers, the elderly, and their families. Currently there is no knowledge available on the process of decision-making in nursing homes when an acute illness occurs, and there is little information available on the attitudes and beliefs of healthcare providers, patients and their families on this important issue.

This is an anthropological field study. The purpose of the research is to investigate the social-cultural factors and other circumstances most likely to influence the evaluation and treatment of acute illness in nursing homes. The goals of the research are to identify, describe and analyze: 1) the social-cultural factors (e.g., marital status and ethnicity) and other circumstances that influence decisions regarding treatment of acute illness in nursing homes; 2) the relationship between the attitudes, beliefs, values, and expectations of healthcare providers, patients, and their families and the decisions made when an acute illness occurs; 3) the process of evaluation and treatment of acute illness in nursing homes;

and, 4) the cultural rules that influence decisions regarding treatment of acute illness.

The investigation uses three research strategies: participant observation, in-depth interviews, and event analysis. Participant observation and event analysis will document the process of decision-making when an acute illness occurs, and identify those factors most likely to influence decision making. In-depth interviews with 105 physicians, nurses, patients, and their families (N = 420) will investigate the social-cultural factors and other circumstances that influence the attitudes, beliefs, and expectations of healthcare providers, patients, and their families. The research will be conducted in three long-term care institutions selected because of their unique characteristics which facilitate investigation of the problem.

This study has significance for important theoretical questions in Medical Anthropology, Medical Sociology, and Gerontology as well as applied significance for healthcare providers (the elderly), and their families.

Research in Mental Retardation: Elderly Mentally Retarded—Population Description and Service Needs

Marty Krauss

Eunice Kennedy Shriver Center for Mental Retardation, Waltham, MA 02254

Sponsor: National Institutes of Health

Purpose—The Eunice Kennedy Shriver Center conducts research on the causes, treatment and prevention of mental retardation in seven departments: Behavioral Neurology, Biochemistry, Clinical Re-

search, Educational Psychology, Genetics, Neuropathology, and Social Science. It also trains professionals in the field of mental retardation and related disorders and provides services to institutionalized

and community-based retarded individuals and their families. The Center is closely affiliated with the Massachusetts General Hospital and other institutions of higher learning. Numerous collaborations between Shriver scientists and investigators at these other institutions place the Center within the mainstream of biomedical, behavioral, and social science research in the area.

Progress—Major new appointments have been made at the Shriver Center in the last three years. Dr. Edwin Kolodny has been appointed Acting Director and is a candidate for a new Harvard Medical School (HMS) professorship established for the directorship of the Center. Dr. Verne Caviness, Jr. has been appointed to the Kennedy Professorship in Child Neurology and Mental Retardation established at HMS in 1982. Dr. Marcel Kinsbourne was appointed Director of Behavioral Neurology, Dr. Marty Kruass, as Co-Director of the Social Science Department

and Dr. Wayne Miller, as Interim Director of the Genetics Department. Core grant funds were used to attract Drs. Kinsbourne and Krauss, and also to recruit Dr. Curtis Deutsch, a behavioral geneticist, Dr. Miyuki Yamamoto, a neuroimmunocytologist, and Dr. Joseph Urbanowski, a biochemist and molecular geneticist.

Research productivity at the Shriver Center is enhanced by core facilities for animal care and glassware washing as well as through the computer, electron microscopy, machine shop, medical illustration, mass spectrometry, monoclonal antibody, and tissue culture facilities. This application seeks funds to add to these services and facilities a P-2 laboratory for molecular genetics, to replace aged central equipment, to purchase new equipment for common usage, to recruit a Director of Clinical Research, and to develop a Neuroendocrine Division within the Biochemistry Department.

Older ESRD Patients: Rehabilitation and Quality of Life

Nancy G. Kutner

Emory University, Atlanta, GA 30322

Sponsor: National Institutes of Health

Purpose—This research will provide needed information about persons ages 60+ who are undergoing treatment for end-stage renal disease (ESRD) and will furnish data on the relation of personal control and illness intrusiveness to the psychosocial well-being of older persons who are characterized by varying circumstances of chronic illness. Kidney function becomes less efficient as people age, and as the entire population ages, increasing numbers of older people will develop ESRD; about 40 percent of all chronic dialysis patients in the U.S. are age 60+, and almost half of all new patients started on dialysis therapy each year are 60+. There is limited information to date about the quality of life of older people who undergo treatment for ESRD. Rehabilitation and quality of life outcomes can be studied from a behavioral science perspective, with attention to the patient's psychosocial problems and assessment of his/her life situation. A better understanding of these issues has implications not only for improved patient care and functioning but also for the difficult ethical question of when dialytic therapy should be terminated or perhaps not initiated.

The study population will be ESRD patients

undergoing treatment in Georgia who are age 60+ as of December 31, 1985. Using the ESRD Network 20 census for that date, a 33 1/3 percent stratified random sample will be selected so that each of the four race/sex groups will be equally represented. Personal interviews will be conducted with patients in the sample; most interviews will take place at the patient's residence. A matched community sample of older persons in Georgia who are not undergoing treatment for ESRD will also be selected and interviewed at their place of residence. These data will allow comparison of quality of life in older ESRD patients with quality of life in persons who are similar in age, race, and sex and who share chronic conditions (e.g., diabetes, cardiovascular disease) and/or age-related impairments such as vision or hearing loss but who are not receiving treatment for ESRD. The analysis will therefore contribute to a better understanding of how the psychosocial well-being of older persons is affected by varying circumstances of chronic illness, as well as furnishing needed information about the rapidly growing segment of the ESRD population that is age 60 or older.

Illness Cognition and Coping in the Elderly

Howard Leventhal

University of Wisconsin, Madison, WI 53706

Sponsor: National Institutes of Health

Purpose—The proposed studies use multi-dimensional scaling and open-ended interviews to uncover the content and underlying dimensions of elderly people's illness cognition: i.e., the cues they use to identify specific illnesses, and their ideas about the cause, time line and consequences of illness. The procedures will also tap how they respond emotionally to illness and how they cope with it. Scales will be developed to measure these factors in clinical populations so we can compare elderly and middle-aged respondents and patients to one another and to patients with four different chronic diseases (hypertension, COPD, arthritis and cancer in remission).

We will study how illness cognition affects emotion and coping, how all three affect selection of symptoms for reporting at clinic visits, how the three affect confusions between different illnesses and how they influence compliance with treatment for problems presented by the patients in comparison to unreported problems uncovered by the practitioner. We will assess whether patients misidentify the nature and cause of illness because their expect-

tations regarding symptom presentations are appropriate to the natural history of disorders in the middle rather than the later years of life.

The final goals are to see whether illness representations and coping are related to feelings of age and to the development of dependency and to unnecessary physical and psychosocial disability. Seeing illness as progressing uncontrollably with age may provoke loss of hope and depressive feelings and lead to apathy and withdrawal from social relationships. These hypotheses will be tested in the four clinical populations of elderly patients.

Finally, an intervention study is proposed comparing a participatory interaction with a standard, treatment control. The participatory interaction is designed to enhance the patient's perception that he/she is an active agent in the identification and treatment of illness problems and to increase his/her feeling of competence, reduce his/her sense of psychological age, and generalize improved coping skills to every-day problems so as to reduce physical and psychosocial disability.

Profile of Visual Function in Low Vision Patients

David S. Loshin

University of Houston-University Park, Houston, TX 77004

Sponsor: National Institutes of Health

Purpose—One of the major problems associated with the management of the low vision patient is the lack of diagnostic tests that accurately reflect the impact of a vision loss. This study will address this problem by investigating the parameters involved in a specific vision task; recognition. Facial recognition is one of the most commonly reported problems for the low vision patient, especially the older low vision patient.

The objective of this research proposal is to develop a battery of clinical tests, the central vision performance profile (CVPP), which will provide the clinician with a more accurate description of the

functional/performance capabilities of the older low vision patient. Problems with recognition have been identified as being one of the major frustrations of individuals with visual impairment. Thus, recognition tasks will be used by the investigators to evaluate performance (or function). The ultimate goal of this project is to gain a better understanding of visual impairment through the development of the vision profile concept, the study of the recognition task, better characterization of residual functional vision, and the improvement of clinical diagnostic services.

The Behavioral Context of Incontinence in the Elderly

Linda S. Mitteness

University of California, San Francisco, CA 94143

Sponsor: *National Institutes of Health*

Purpose—Urinary incontinence (UI) is a problem for a significant portion of the community-living elderly. Two of the most striking and consistent findings of my earlier research on UI in the relatively healthy elderly have been a) that management strategies for UI depend on the presence of coexistent illnesses or disabilities, and b) that UI, despite being recognized as troublesome, is cognitively seen to be a normal part of old age and therefore irremediable.

This study extends the investigation of behavioral and cognitive contexts of UI to a very different population, the frail, homebound elderly, and asks: How do multiple and/or severe coexistent illnesses influence the management of UI? What types of cognitive organizational strategies are used by this group of elderly who are heavily embedded in a health service network? It consists of careful description of: 1) the patterns of UI in this population; 2) the illness or disability contexts, the physical environment contexts and the social contexts in which UI occurs; and, 3) the cognitive organizational

strategies used by the incontinent elderly and their caretakers. Further, several analytic questions are posed concerning hierarchies of disorder and cognitive organizational strategies.

A stratified, random sample of 200 homebound elderly clients will be drawn from the client list of the Visiting Nurse Association. A case study of each client will be constructed through interviews with the client, the client's family and/or caretakers, the VNA staff responsible for the client's care, and the client's referring physician. Each case study will start when the client begins receiving services and monthly follow-up will be conducted for a six-month period.

The findings of this study will provide information about the behavioral contexts of urinary incontinence in the frail elderly. This knowledge will be useful for theory development concerning hierarchies of disorder and cognitive organizational strategies about age-related disorders as well as for interventions focusing on reducing the medical, social and personal burden of urinary incontinence.

Teaching Nursing Home: Modification of Exercise Capacity in the Elderly

Joel D. Posner

Medical College of Pennsylvania and Philadelphia Geriatric Center at Friedman Hospital, Philadelphia, PA 19129

Sponsor: *National Institutes of Health*

Progress—This study is testing the hypothesis that a simple program of regular exercise for relatively healthy elderly individuals will result in tangible improvements in exercise capacity and physical and psychosocial health. The study will use 360 physically normal adults between the ages of 60 and 90 years. Initial and subsequent evaluations for exercise capacity will include the anaerobic threshold, maximal aerobic power ($\text{VO}_2 \text{ max}$), and other common exercise parameters such as heart rate.

Aside from the exercise measurements, a full

battery of physiological tests will be used to evaluate resting responses before and after exercise training, including pulmonary and cardiac functions. In addition, psychological tests and healthcare-use data will be obtained. The major measurements (exercise, resting, and psychological data) will be determined before exercise training and after 4 and 12 months of training. The subjects will be assigned to one of the following groups: 1) the center and home exercise group; 2) the center only exercise group; and, 3) a control group.

Geriatric Medicine Academic Award

Leif Sorensen

University of Chicago, Pritzker School of Medicine, Chicago, IL 60637

Sponsor: *National Institutes of Health*

Purpose—The Pritzker School of Medicine, University of Chicago, has designated Dr. Leif B. Sorensen, Professor of Medicine, as its candidate for the Geriatric Medicine Academic Award. A program for development and continuous strengthening of teaching and research in gerontology and geriatric medicine is proposed, with the following objectives: 1) to expose all students to gerontology/geriatrics by incorporating topics on aging into the required courses of the preclinical curriculum; 2) to develop an elective course “Introduction to Geriatrics” in the sophomore year; 3) to incorporate segments of geriatric medicine into the major clinical clerkships; 4) to develop a 2-month elective for senior students “Comprehensive Geriatrics”; 5) to establish a Geriatric Outpatient Clinic and an Inpatient Consultation Service as educational and clinical care facilities; 6) to establish an “Office of Geriatrics” as a

center for administrative and educational activities; 7) to provide house-staff with opportunities for training in geriatric medicine in the ambulatory setting; 8) to offer a 2-year fellowship training program aimed at promoting careers in academic geriatric medicine; 9) to conduct Grand Rounds and CME courses to increase the awareness of faculty and practitioners to the unique medical and psychosocial problems of the elderly; 10) to foster the development of research programs in aging; 11) to develop promising young faculty interested in committing their careers to geriatrics; 12) to provide an opportunity for the awardee to acquire additional skills with a view toward enriching the curriculum; and, 13) to facilitate interdepartmental and multidisciplinary teaching and research in the field of aging.

Geriatric Dentistry Academic Award

Hilde H. Tillman

Tufts University, Boston, MA 02111

Sponsor: *National Institutes of Health*

Purpose—It is the specific aim of this program to create a Division of Geriatric Dentistry at Tufts University School of Dental Medicine and to develop a comprehensive interdisciplinary didactic and clinical curriculum. It will be allied with Forsyth Dental Center, the developing Medical Geriatric program, the Human Nutrition Research Center on Aging, the Aging Activities of the Department of Psychiatry and the Veterinary School. This division will present the complexity of aging to undergraduate dental students, graduate dental students, dentists, dental hygienists, and staff. The interdisciplinary faculty will include all dental specialties. The Medical specialists will include Gerontology, Physical Medicine and Rehabilitation, Nutrition, and Psychiatry. The allied professionals include Social Service, Occupational Therapy, Physical Therapy and Speech and Hearing. The curriculum will be interwoven throughout the four years. The program consists of

a special lecture series. Second semester of the second year, required seminars, required clinical assignments in the 4-chair geriatric area and the Chelsea Soldier's Home.

The outreach activities include: the Hebrew Rehabilitation Center, Community Residencies, nursing homes, and bedside dentistry with portable equipment; research activities in all phases of Gerontology and Geriatric Dentistry; and, a strong continuing education program for dentists, postdoctoral students and staff. Particular emphasis is placed on faculty development in Gerontology and Geriatric Dentistry. The program evaluation will insure our long-term objectives: to train dentists competent in rendering total patient care to this growing segment of our society and to accept the obligation and challenge through continuing growth and development.

Cutaneous Mechanoreceptor System

Ronald T. Verrillo

Institute for Sensory Research, Syracuse University, Syracuse, NY 13244

Sponsor: National Institutes of Health

Purpose—Information processing by cutaneous tactile systems may be utilized when the effectiveness of a conventional channel is limited, as in high noise environments; when existing channels are overtaxed, as in jet and space control systems; or when existing channels suffer a deficit, as in the sensory losses of deafness and blindness. Of increasing interest are the sensory characteristics associated with advancing age and those associated with pathologies that may affect neural functioning. There are still sizeable gaps in our knowledge of important fundamental characteristics of the cutaneous sensory systems.

The aim of the proposed experiments is to extend

our understanding of the psychophysical characteristics of responses to vibrotactile stimulation in humans. Intimately related to this is a better understanding of the morphological structure of the receptors involved. We also plan to investigate the fine structure of the Pacinian corpuscle. The experiments fall into five general problem areas: spatio-temporal aspects of vibrotactile sensation; sensory interactions among cutaneous mechanoreceptor systems; interaction between vibrotaction and other sense modalities (cutaneous and noncutaneous); characteristics of cutaneous sensory systems as a function of aging and handedness; and, the detailed anatomical features of the Pacinian corpuscle.

Morbidity Risk Assessment in the Elderly

Ben T. Williams

University Park Pathology Associates, Urbana, IL 61801

Sponsor: National Institutes of Health

Purpose—We plan to design, implement, and test a health risk assessment computer program to generate estimates of the probability of hospitalization, disability, and other undesirable health consequences as a function of medical history, laboratory findings, and health habits. The program, used in conjunction with health examination programs for persons aged 60 and above, will facilitate appropriate screening diagnostic tests and risk reduction interventions. Estimates of health consequences from risk reduction will be used to motivate and reinforce behavior changes.

Phase I is a feasibility study to evaluate existing research regarding the association between health habits and consequences among the elderly and

research on the effectiveness of risk reduction activities in this population. Phase I also includes preliminary analysis of public use datatapes from the National Center for Health Statistics. Phase II includes further statistical analyses, risk factor quantification, development of program specifications, software production, and instrument testing in a clinical setting. Phase III is devoted to marketing the program to medical sites where health risk appraisal is commonly used as a health education intervention; the 1984 American Hospital Association questionnaire reported that 17 percent of respondents use health risk appraisal in community outreach programs.

Cooperative Group Outreach Program (ECOG)

Marvin Zelen

Frontier Science and Technology Research Foundation, Inc., Brookline, MA 02146

Sponsor: *National Institutes of Health*

Purpose—The major aims of this project are: 1) to carry out multi-institutional “state-of-the-art” clinical trials with patients being treated in community hospital settings by expanding and maintaining the ECOG community hospital network; 2) to involve community hospitals and their patients in studies relating to cancer prevention and epidemiology; 3) to implement an educational program to meet the special needs of community physicians, nurses and data managers; 4) to develop a micro-computer

network which will lead to increased communication and hence greater participation by community affiliates; 5) to evaluate the impact of this Program on community hospitals with regard to patient outcome (survival, toxicity, etc.); 6) to study the special problems of the elderly cancer patients to determine if treatment in community hospitals is different from major cancer centers; and, 7) to carry out methodological research which will enhance the goals described above.

Assessment of the Spatial and Temporal Characteristics of Vision as a Function of Age

Edward J. Rinalducci, Ph.D.

College of Arts and Sciences, Department of Psychology, University of Central Florida, Orlando, FL 32816

Sponsor: *Research Service, VA Medical Center, Decatur, GA 30033*

Purpose—The main objective of the research reported here was to examine changes that occur in the spatial and temporal properties of the human visual system as a function of the aging process. It was proposed that data of a preliminary nature be gathered on spatial contrast sensitivity, visual persistence, and color vision differences for a group of young adult observers (18-29), middle-aged (30-49), and older observers (50-75).

In order to assess the visual system's limitations in resolving changes in light intensity over space, one can measure the observer's threshold for detecting sine wave gratings as different from uniform stimuli for a range of spatial frequencies (i.e., spatial sine wave gratings varying in the number of cycles per degree of visual angle). These measurements produce a spatial contrast sensitivity function (CSF) which provides a basis for predicting the apparent brightness of many types of stimulus configurations. The CSF has a characteristic shape for the normal adult visual system and should vary in level or shape as a function of age/or pathology.

The temporal characteristics of the human visual system in the present case refer to how it responds to changes in the perceived duration of the visual

stimulus (e.g., a spatial sine wave grating). The temporal response characteristics of the visual system can be examined through the phenomenon of visible persistence. Visible persistence refers to the existence of an internal representation of a briefly presented stimulus, which remains available (i.e., persists) to the subject after the offset of the stimulus.

Progress—A visual assessment battery has been developed for use with the age groups of interest. This battery includes the following tests and/or measurements: 1) the Vistech Contrast Test; 2) a measure of Snellen acuity; 3) the Ishihara Color Vision Test; 4) The Tritan Plate (F2 test) developed by the Naval Medical Submarine Research Laboratory—New London, CT; 5) the Munsell-Farnsworth 100-hue test; and, 6) a measure of visible persistence.

Visible persistence will be measured by flickering a grating of a given spatial frequency (e.g., 1, 3, and 12 cycles per degree) at a rate that is just fast enough to be seen as fused (i.e., until a critical fusion frequency is obtained). This technique will allow a rapid and relatively undemanding collection of data

using older observers. A test for visible persistence should be useful for determining spatio-temporal changes in the visual system with age.

Future Plans—Initial data collection, which began at the Georgia Institute of Technology, will be completed at the University of Central Florida.

Future research in this area will include an examination not only of visible persistence, but also the effects of masking of one spatial grating by another, the effects of transient adaptation on visibility loss (losses due to sudden increases or decreases in luminance level), and the effects of foveal loading on peripheral visual sensitivity as a function of age.

Environmental Influences on Behavior of Patients with Alzheimer's Disease

Mavis Claytor Ford, R.N., M.S.N.; Jeanne C. Fox, R.N., M.S.N., Ph.D.; Sandra Fitch, R.N., M.S.N.; Anne Donovan, R.N., M.S.Ed.

Veterans Administration Medical Center, Geriatric Unit, Salem, VA 24153

Sponsor: VA Medical Center, Salem, VA

Purpose—The purpose of the investigation was to explore the effects of lighting and sound on the agitated and confused mealtime behaviors of Alzheimer's patients. The study was based on documented observations by the nursing staff of patient behaviors related to their obvious lack of response to verbal and pictorial stimulation, the apparent calming effects of a power outage on their agitation, as well as the absence of effective treatment for confusion and demented conditions.

Progress—Sixteen confused patients on a long-term ward were videotaped during weekday mealtimes for 8 consecutive weeks. Videotaping was accomplished unobtrusively with a portable camera, using a multiple baseline design study. Two light and three sound environmental manipulations were introduced for one week at mealtimes. The two light conditions consisted of low level pink lighting and high level ceiling fluorescent lighting. The three sound conditions were white noise, country and western music, golden journey, and nature sounds.

Control conditions included the naturally occurring voices of staff, patient sounds, and daylight with fluorescent lights. Recorders observed and coded the videotaped behavior of each subject for the entire hour-long period. Ratings of the patient's behaviors were made according to identification of criterion behaviors selected in pre-experiment viewing of tapes made at mealtimes, which had recorded the following behaviors: handclapping, mouth-to-hand repetitive movements, leg slapping, grabbing at toes, picking feet, pulling up and back in chair, coughing, moaning, shrieking laughter, foot banging,

and "ah" sounds. Eight behaviors were analyzed for frequency, as well as intensity during baseline periods, and compared with behaviors during experimental periods.

Results—Analysis revealed a decrease in frequency and duration of motor criterion behaviors with both low level light, golden journey, and nature sounds. The Haycox rating scores of dementia for patients ranged from 36 to 47. The recorded food consumption increased and the length of eating time decreased (only nature sounds could be correlated with increased food consumption and decreased eating feeding time). Decreased food consumption was documented with country and western music.

Future Plans/Implications—Since this limited study did show positive changes in behavior, we plan to continue exploring the effects of light and sound stimuli on the behavior of Alzheimer's patients in a naturalistic setting. Plans include introducing stimuli such as pre-warmed beds at bedtime and breakfast food odors upon arousal. Also, we are in the process of developing a behavioral checklist for patients with Alzheimer's disease and other dementia-producing illnesses.

It appears that low level lighting may well be an important environmental factor to be considered in designing treatment centers for confused elderly patients. Other environmental factors such as temperature and odors need to be investigated for possible inclusion in the design of these treatment centers. An article describing this project was published in *Nursing Times*, January 7-13, 1987.

XV. Sensory Aids

A. Blindness and Low Vision

1. General

The Use of the Electretinogram to Predict Retinal Cell Activity

Kent Davey; Barrett Thompson; Shimin Wang; Art Koblasz

School of Electrical Engineering, Georgia Institute of Technology, Atlanta, GA 30332 and Veterans Administration Medical Center, Decatur, GA 30030

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objective of this research is the non-invasive prediction of retinal cell activity. More specifically, the goal is to assess the healthiness of discrete regions of the retina. The diagnosis of certain areas of the retina is sought via the use of the electretinogram (ERG). Two protocols were developed, both theoretically and experimentally. The first involves multiple measurements of electrical and experimentally. The first involves multiple measurements of electrical potential over the cornea and schlera in response to a single flash stimulus. Using integral field theory and some simplifying assumptions as to the constitution of the intra- and extraocular region, a prediction of a retinal activity commensurate with a corneal potential scan is realized through a matrix inversion. The matrix is an embodiment of the link between the sources (which are jumps in electrical potential across the pigment epithelium) and the potential on the front of the eyeball, i.e., the cornea. The experimental procedures used to realize the multiple corneal potential

measurements along with the necessary circuitry and results are presented.

The second protocol involves a single potential measurement on the cornea as is commonly done clinically at present, but with multiple flash stimuli. The technique is ultimately dependent on the patient's ability to focus on the external flash stimulus pattern. The individual components of the ERG, which are directly associated with specific parts of the stimulus pattern (and thus, localized regions on the retina), are stripped from the composite ERG using signal correlation techniques. At the heart of this approach is the requirement that the isolated stimuli are each individually uncorrelated to one another, i.e., they are random in time. An analytical ERG is constructed to test the efficacy of the use of single and double kernel correlations for predicting retinal impulse responses. The theory is applied experimentally to a three-flash stimulus ERG setup with a large bullfrog.

Pupillary Function in Elderly Individuals with Impaired Night Driving Vision

Robert W. Lorance, M.D.

Hines Veterans Administration Hospital, Hines, IL 60141

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The goal of this research is to determine the cause of poor night driving vision in elderly individuals. Age-related alteration of pupillary func-

tion is a variable which may impact on the adaptive visual ability of the elderly in situations where light intensity changes rapidly, as when driving at night

against oncoming traffic.

Many people over age 60 describe difficulty seeing when driving at night, to such an extent that they feel unsafe while driving. These people either continue to drive and pose a threat to their own safety and that of other drivers, or they restrict their driving to daylight hours and thus are limited in their mobility and ability to participate in social functions at dusk or at night. A significant proportion of the veteran population falls into this age category.

A solution to this problem is to identify the cause of impaired night driving vision by examining the physiology of vision as relates to night driving. Because night driving involves rapid changes in light intensity (as in driving against oncoming traffic),

and because alteration in pupil size is the physiologic means of regulating the amount of light entry into the eye, this study will establish whether changes in pupillary function are related to this problem. If this relationship exists, it may provide an impetus for better illumination of roads and highways to ensure the safety and improve the quality of life of the elderly. To date, 140 volunteers have been enlisted to participate in this study, as funding is made available for its implementation.

The tasks of this study are to quantify the prevalence of poor night driving vision and establish any relationship between this symptom and abnormal pupillary function.

Predicting the Visual Abilities of Partially Sighted Persons

John Trimble, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Hines, IL 60141

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Clinicians prescribe aids and therapies for visually impaired persons on a daily basis. However, these prescriptions and therapies lack a sound theoretical foundation. It is generally accepted that psychophysical measures of visual function tell us something about how a person sees. However, there is little evidence that they tell us how well a person can perform various visually oriented tasks. Accordingly, a theoretical model is needed to guide the treatment and rehabilitation of persons with severely impaired vision.

There is no set of measures of visual function that accurately predicts people's ability to perform various tasks. Previous research has demonstrated that some measures (contrast sensitivity, visual acuity or visual fields) can be used to predict performance on some tasks. However, these predictions do not always hold for other tasks. The basic problem lies in reducing measures of visual function to a form that is a robust predictor of a person's ability to perform a wide variety of tasks.

Progress—I have attempted to solve this problem by reducing measures of visual function to a parametric form suitable for multivariate analysis. These data will be correlated with data on people's ability to perform various tasks that will be obtained by survey. By correlating the ability to perform a task

with variables in the feature set of measures of visual function, I hope to obtain a robust set of predictors that can be used by clinicians to prescribe the course of treatment for persons with severe visual impairments.

Preliminary Results—I have recently replicated earlier studies on the effect of contrast on letter detection and recognition. I subsequently extended these studies to determine the relationship of the contrast sensitivity function. In contrast to previous studies, I have found that the relationship depends on the letter's medium and high spatial frequency components rather than their fundamental spatial frequency components as reported by other studies. This finding has led me to develop protocols for additional studies to determine the precise band of spatial frequencies that affects people's abilities to identify letters. It has also led me to develop techniques for image enhancement that are based on expanding contrast rather than increasing the magnitude of certain spatial frequency components.

Future Plans—During the project's final year, I will conduct studies on persons with severely impaired vision to examine the relative importance of certain spatial frequencies in letter recognition and to test the efficacy of contrast enhancement techniques.

Hearing Impaired Blind Veterans

Jaclyn B. Spitzer, Ph.D.

Veterans Administration Medical Center, West Haven, CT 06516

Sponsor: VA Department of Medicine and Surgery Funding

Purpose—The Eastern Blind Rehabilitation Center (EBRC) for the Veterans Administration is located at the VA Medical Center in West Haven and provides evaluation and training to patients from the entire Eastern Seaboard and Puerto Rico. Since 1983, all patients admitted for blindness or low vision rehabilitation have undergone audiologic evaluation. The purpose of this report is to present the results of the evaluations for the four-year time period, including hearing profiles and aural rehabilitative recommendations. Auditory needs of the visually-impaired veteran, and the role of audiologists in their care are discussed.

Progress—All patients admitted to EBRC from 1983-1987 were evaluated audiologically. As of this submission, the number of patients in the sample was 178 (approximately 250 are expected by the end of 1987). The data for the first 113 subjects is summarized below to provide insight into early trends.

The mean age of the present sample was 56.84 (SD = 13.72; range = 22-89). The predominant causes of blindness included: diabetic retinopathy; trauma; glaucoma; retinitis pigmentosa; macular degeneration; and glaucoma. Upon admission to EBRC, all patients were referred to Audiology. Procedures were standard audiometric evaluation, including: pure-tone air- and bone-conduction thresholds; spondee thresholds; speech discrimination for W-22 lists; site-of-lesion tests, when indi-

cated; and informational counseling regarding hearing loss. Patients were routinely asked if their hearing was an impediment to conversation, comprehension in the classroom setting, and orientation in mobility. Based on appropriate audiometric findings, referral for hearing aid evaluation was initiated. Means and standard deviations were calculated for audiometric thresholds, for pure tones and speech. Frequency counts of types of etiologies of blindness, reports of noise exposure, and hearing aid referrals were totalled. The percentage of the group was calculated for each of the latter factors.

Preliminary Results—The group was characterized by high frequency sensorineural hearing loss. Hearing loss was observed in 91 percent of the patients evaluated. The degree of loss was sufficient to warrant (new) aural rehabilitative intervention in 31 percent of the first 113 cases.

Future Plans/Implications—At the observed rate of need for new hearing aids (i.e., previously unfit with aids) and auditory training, a significant role for audiologists in programs of rehabilitation of the adult visually-impaired is readily seen. Furthermore, in view of the significant number of hearing impairments seen that were not amenable at this time for hearing aid use, the importance of education of the visually-impaired regarding audition and the effect of hearing loss on mobility is apparent.

A Voice-Output Questionnaire Administrator

David L. Jaffe, M.S.E.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Center Core Funds

Purpose—This project employs a computer-controlled DECtalk speech synthesizer to administer, score, display the results of, and maintain data from, a standard psychological test (POMS, the Profile of Mood States) for visually impaired and blind individuals.

Progress—To measure and compare the mental state of individuals, the Bipolar Form of the Profile of Mood States (POMS) has been developed by the Educational and Industrial Testing Service to quantify six selected bipolar subjective mood states. In this test, each mood consists of two extremes, one

represented by the positive aspects of the mood, the other by the negative aspects (such as happy-sad). Each of the six moods (composed-anxious, agreeable-hostile, elated-depressed, confident-unsure, energetic-tired, and clearheaded-confused) are measured by analyzing the test-taker's level of agreement to positive and negative mood indicator phrases such as "cheerful" or "downhearted." While POMS was developed to evaluate established mood states and feelings reported by both normal and psychiatric patients, the principal contemplated use of this test at the Western Blind Rehabilitation Center is to evaluate the relative effectiveness of various training programs in reducing negative moods while enhancing the positive ones.

The POMS test cannot be administered in the traditional manner to patients who are blind or have visual impairments, since neither group has the visual acuity to read the individual phrases, nor the ability to indicate their choice on the answer sheet. Currently, a staff member reads the phrases to these individuals, queries them for their response, and then fills in the appropriate box on the answer sheet. Later, the answers are hand-scored and a profile produced. Although the time for a sighted person to take the test is only five minutes, the staff time required to administer the test to an in-patient is often double or triple this. Also, the current manual method of scoring and graphing the results is time-consuming. Other staff duties often interfere with these tasks, so the motivation exists to reduce the number of these tests given, rather than to increase their administration during the patients' course of therapy and training. The whole process is therefore a labor-intensive one, since it requires administering, scoring, and graphing the results.

The prototype system consists of an IBM XT-compatible computer with printer, a DECtalk speech synthesizer, and appropriate software. The DECtalk unit has been chosen because it produces speech which is readily understood by those who have no computer experience.

During test-taking using the DECtalk, the software first provides verbal instructions to the patient and then starts the test. Each mood phrase is presented in turn, and a response is solicited. Responses are made by the patient by either pressing keys on a standard keyboard or on a set of large mushroom-

shaped buttons. If, after a given time, no answer is received, the computer reissues the phrase. All patient responses are confirmed, and can be changed if a mistake is made.

At the completion of the test, the computer performs all the necessary scoring, collation, and computation required to produce a dated graph of the mood state profile. This result is then compared to others taken previously, and is eventually placed in the patient's medical record.

It is estimated that the verbal administration of this test would take fifteen minutes, while the computerized administration of the questionnaire will require just five minutes. Scoring and the printing of the results would take an additional minute or two; an appreciable saving over the five-minute manual method. In addition, more accurate results are anticipated, since any human bias in verbally asking the questions and recording the results of the questionnaire would be eliminated.

Preliminary Results—The initial software phase of this project has been completed. The first volunteers and test subjects have been selected and testing has begun. At this early stage, no conclusions can be made as to the accuracy or repeatability of this voice-output method of testing.

Future Plans/Implications—Two positive results are anticipated upon completion of the pilot phase of this project. First, the project will provide the Western Blind Rehabilitation Center with needed data concerning the effect of the courses and therapy it provides to its patients. Second, it will provide information on the utility of computer-based speech synthesizers in administering psychological tests to visually impaired and blind individuals. This data should also prove useful in the development of other systems that disseminate information to callers in a similar manner.

Publications Resulting from This Research

Rehabilitation Applications of the DECtalk Speech Synthesizer. Jaffe DL, *Computer Technology for Disabled Conference*, Palo Alto, March 1986.

A Voice-Output Questionnaire Administrator. Jaffe DL, *Voice I/O Systems Application Conference*, Alexandria, VA, September 1986.

The Physical Correlates of Tactual Perception

John Trimble, Ph.D., and Rebecca Hollyfield, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Hines, IL 60141

Sponsor: VA Rehabilitation Research and Development Center Core Funds

Purpose—Although tactual symbols are frequently used in materials for blind persons, there is no theoretical framework for developing symbols that are easily understood or recognized. Accordingly, most tactual symbology is designed by trial and error. Unfortunately, this has resulted in material that is not easily understood by many blind persons.

Before we can design meaningful tactual symbols, we must understand the physical features that affect how people recognize and interpret them. Although considerable research has been done on this problem, no one has yet determined the features that most significantly affect perception of tactual symbols.

We are attempting to solve this problem by describing tactual forms on the basis of the Fourier transform of a function describing the tangent angle to their boundaries at regularly spaced intervals. The transformation yields a set of variables called Fourier descriptors and it has been used successfully to solve many pattern recognition problems. We hypothesized that if the mechanisms of tactual perception are similar to algorithms for pattern recognition, then Fourier descriptors may be used to predict perceived qualities such as similarity or complexity. We believe that if our hypothesis is correct, Fourier descriptors may also be used to assess the identifiability or discriminability of existing or newly-developed tactual symbols.

Progress—We created a set of six tactual forms. The shape of each form was determined by a random process and the forms vary in the number of line segments that they contain. We then analyzed the forms to determine their Fourier descriptors.

We subsequently asked 30 subjects to rate the

complexity of each form and the similarity of all pairs of the six forms. The subjects examined the forms both tactually and visually. We found that certain bands of Fourier descriptors were highly correlated with the subjects' ratings of complexity and similarity. We found that complexity ratings were highly correlated with high-frequency bands of Fourier descriptors, regardless of how the forms were viewed. We also found that the band of Fourier descriptors that was most highly correlated with subjective ratings of similarity depended on whether the form was viewed tactually or visually. Visual similarity ratings were more highly correlated with high-frequency bands of Fourier descriptors and tactual similarity ratings were more highly correlated with low-frequency bands. We also found that tactual ratings of similarity were highly dependent on the form's area. Our data suggest that it is much more difficult to detect differences between small forms than large forms. Interestingly, this finding does not hold for forms that exceed a certain area which suggests that different perceptual mechanisms may be used for large forms.

Future Plans—Our next task is to repeat our studies, using subjects who are blind. This will tell us if prior tactual experience has any effect on similarity judgments and the relationship between Fourier descriptors and similarity ratings. After we have completed these studies, we will test the robustness of our measurement by using it to predict the perceived similarity of commonly used tactual symbols. This will give us an idea of how useful the technique is for making *a priori* judgments on the ease with which blind persons can perceive tactual symbols.

Model-Based Image Enhancement for the Visually Impaired

Eliezer Peli

Eye Research Institute Retina Foundation, Boston, MA 02114

Sponsor: National Eye Foundation

Purpose—Image enhancements potentially provide elderly macular disease and cataract patients better use and enjoyment of printed photos and television. A variety of equipment and techniques exist for enhancements, but there is currently no systematic method of designing appropriate techniques.

Threshold and suprathreshold contrast sensitivity functions (CSF) provide more detailed description of pattern vision losses than standard acuity and visual field data. CSFs potentially provide a basis for image enhancements tailored to losses of disease classes or individuals. This potential will be investigated in the context of spatial frequency filter visual models. Image enhancements will be based on measurements of patients' threshold and suprathreshold CSFs. The value of filter models in

this context will be determined by measuring the patients' performance with the enhanced images. Patients with monocular cataract or monocular macular disease will be evaluated.

The patient's threshold CSF obtained with the good eye will be compared with that obtained with their other eye to determine a degradation transfer function. The inverse of this function will be applied as a filter to pre-emphasize spatial frequency bands in face photographs. Suprathreshold CSFs will be used similarly; in this case the specific enhancement filter applied will depend upon local contrast in the input image. Recognition of learned and familiar (celebrity) faces and discrimination tests will be used to evaluate the benefit of the various enhancement schemes.

Functional Vision and Clinical Tests in Low Vision

Ian L. Bailey

University of California, Berkeley, CA 94720

Sponsor: National Eye Institute

Purpose—Our broad objective is to improve the quality of low vision care. The clinician attempting to help the low vision patient needs to have clinical tests that can predict the patient's disability at functional tasks. In this project, a battery of clinical tests and a series of tests of functional vision will be assembled. These tests will be applied to two groups of subjects who show substantive changes in functional ability with changes in illumination. One group will have macular degeneration, the other retinitis pigmentosa. An added normal, age-matched control group will also be used. Controlling illumination will provide changes in the subjects' functional disabilities. The clinical test scores associated with particular levels of disability will be determined for each subject. The strength of the association between test scores and disability levels will provide the predictive power of the clinical tests.

The functional tasks to be tested are reading, face

recognition, and mobility. The clinical tests considered are of: 1) visual acuity: grating, single letters, letter charts, work reading, and low contrast letter charts; 2) contrast sensitivity: CSF's small and large field, edge detection, Arden gratings (with suitable controls), vistech VCTS and Bailey's contrast test; 3) visual fields: Dicon perimetry, Freidman field analyzer, Amsler Grid, and Reversed Contrast tangent screen; 4) color vision: with standard, desaturated, and large area panel D-15 tests; and, 5) as appropriate, there will be added testing to better define the extent and nature of the visual loss in cooperation with Professor Enoch's laboratory.

Correlations and multiple correlations between clinical test scores and functional abilities will be evaluated. Recommendations will be made advising clinicians which tests are most appropriate for predicting capabilities at the different functional tasks.

Sonar Sensory Substitution—Spatial Behavior in the Blind

Randolph D. Easton

Boston College, Chestnut Hill, MA 02167

Sponsor: National Eye Institute

Purpose—A program of investigation is outlined which will explore the effect of a new generation sonar sensory aid—the Trisensor—on blind people's ability to spatially "update" or keep track continually of their changing position relative to their surroundings during locomotion. In addition, the project will assess the extent to which the sonar sensory aid can substitute for vision in the control and regulation of balance and postural stability in blind people.

The major study will assess the ability of congenitally totally blind adults and school-age children to learn to use the Trisensor to locate targets in large scale space (5m arc). The subjects' ability to use the Trisensor will be compared to their ability to locate the targets when they are emitting sound. The effects of both Trisensor and natural sound localization training on more generalized tests of spatial cognition will also be determined. The prototype test entails familiarizing subjects with an array of targets by walking them to each target. Subjects would then be led to one of the targets and asked to indicate the direction and distance of

another target, the location of which they had not directly experienced from their new position.

Blind people experience difficulty with this task, presumably because they have not had past experience with dynamic visual information which is produced during locomotion and specifies an observer's changing perspective. Since the returning echoes of the Trisensor afford a moving observer acoustic flow patterns regarding the position of objects in the distal world, it is hypothesized that the use of the aid will enhance spatial updating ability.

It is now known that vision also plays a critical role in controlling human balance. Because blind people have well-documented difficulties with balance, it is important to determine whether the Trisensor can substitute for vision in this capacity. A battery of balance tests administered before and after Trisensor and natural sound localization training will permit the assessment of the effect of sonar sensory aid and natural sound on the control and regulation of balance and postural stability.

Electronic Braille Page Output Device Using Nitinol SMA

A. David Johnson

Tini Alloy Company, Berkeley, CA 94705

Sponsor: National Eye Institute

Purpose—The research objective is a page-format electronically controlled Braille output device for blind computer users. Each dot, six of which constitutes a Braille character, is actuated by a short length of fine-gauge wire. The wire is made of a shape-memory alloy: Nitinol. This method has been proved feasible for a single dot.

Further research will combine six dots into a standard size Braille character module and incor-

porate character modules into a multiple-line format. Methods of wire-drawing will be developed for producing the small-diameter Nitinol wire required. A printed circuit board for insertion into an IBM-PC (or alternatively for the Apple-2E) will be developed for driving the output device, along with appropriate software to demonstrate the capability of the system.

Psychophysics of Reading—Normal and Low Vision

Gordon E. Legge

University of Minnesota, Minneapolis, MN 55455

Sponsor: National Eye Institute

Purpose—We will measure how reading by observers with normal and low vision depends on the stimulus properties of text. The stimulus properties of text that are necessary for normal observers to read are defined to be the visual requirements of reading. Our research has three primary goals: 1) to measure the visual requirements of reading under conditions that are relevant to low vision; 2) to develop simple tests of visual capacity that can predict reading performance of low-vision observers; and, 3) to discover the influence on reading performance of stimulus properties, opthalmic disorder, acuity deficit and field loss for low-vision observers.

We will use psychophysical methods in five series of experiments. First, we will discover the visual requirements of normal reading, with special emphasis on contrast and spatial frequency. We will also measure the visual requirements of letter, word, and picture recognition. Secondly, we will seek to develop improved means for measuring contrast

sensitivity, based on recognition rather than detection, to quantify the visual capacities of low-vision observers. Thirdly, we will determine whether recognition tests of contrast sensitivity and knowledge of the visual requirements of normal reading can be used together to predict reading performance of low-vision observers. Fourthly, we will measure effects of several special factors of low-vision reading—glare, contrast reversal, wavelength, and ability to focus. Finally, we will test hypotheses that attempt to explain psychophysical properties of reading in terms of known properties of pattern vision.

The research will be useful in three ways: 1) improved understanding of the sensory constraints of normal reading; 2) the development of systematic techniques for testing low-vision capacity, with the aim of specifying image properties required of an appropriate reading aid; and, 3) in establishing necessary stimulus characteristics for new low-vision reading aids.

Analysis of Navigation Without Sight

Jack M. Loomis

Community and Organization Research, University of California, Santa Barbara, CA 93106

Sponsor: National Eye Institute

Purpose—This research is concerned with non-visually guided navigation by blind and by blindfolded observers. All experimental tasks involve locomotion through a work area of 30m by 30m; some segments of travel will involve guidance by the experimenter while others will involve free locomotion.

The experiments will attempt to analyze navigation performance into two major components: 1) perception of distance and heading changes; and, 2) cognitive representation of surrounding space and transformations of this representation during locomotion. Precision of the first component will be assessed by simple tasks such as estimation, reproduction, and bisection of distances or angles.

The second component will be assessed by more complex tasks, such as having the observer: 1) return to the start point after being guided over two legs of a triangle; and, 2) proceed directly between two locations that are known previously by traveling between each and a common origin.

The research will evaluate the utility of a stereophonic auditory display as an interface to a digital map system. It will also add to our understanding of the apprehension of space without vision and will aid in the development of an effective display to be used in conjunction with those digital map/navigation systems which are coming into use and may some day prove useful for the visually impaired.

Profile of Visual Function in Low Vision Patients

David S. Loshin

University of Houston, University Park, Houston, TX 77004

Sponsor: National Eye Institute

Purpose—One of the major problems associated with the management of the low vision patient is the lack of diagnostic tests that accurately reflect the impact of a vision loss. This study will address this problem by investigating the parameters involved in a specific vision task: recognition.

Facial recognition is one of the most commonly reported problems for the low vision patient, especially the older low vision patient. The objective of this research proposal is to develop a battery of clinical tests, the central vision performance profile (CVPP), which will provide the clinician with a more accurate description of the functional/performance

capabilities of the older low vision patient. Problems with recognition have been identified as being one of the major frustrations of individuals with visual impairment. Thus, recognition tasks will be used by the investigators to evaluate performance (or function).

The ultimate goal of this project is to gain a better understanding of visual impairment through the development of the vision profile concept, the study of the recognition task, better characterization of residual functional vision, and improved clinical diagnostic services.

Prediction of Symbol Recognition in Low Vision Patients

Michael A. Morris

Illinois College of Optometry, Chicago, IL 60616

Sponsor: National Eye Institute

Purpose—This study will correlate the results of clinical measures of contrast sensitivity, visual acuity, and visual fields with the ability of low vision patients to identify symbols correctly at intermediate distances. The study aims to develop these tests so that they correlate well with performance in visual tasks, and to determine the role of apparent size and contrast in the identification of objects by patients under several conditions of visual impairment.

The long-term benefits will be derived through improved diagnosis of visual disabilities and improved low vision therapy. Approximately 100 subjects ranging from 20 to 80 years in age will be used in the study, and will have lost sight to one of three diseases: retinitis pigmentosa, diabetic retinopathy, or maculopathy. Forty normally-sighted, age-matched control subjects will also participate in the study. Each subject will have his acuity measured, using the acuity chart employed in the Early Treatment Diabetic Retinopathy Study at a test distance of 2.4 meters, and a background luminance of 100 cd/m².

The results will be recorded as log minimal angle of resolution (MAR). Visual fields will be measured using a Humphrey Model 610 automated perimeter. Threshold static fields will be determined for the central 40 degrees of vision, and the results will be recorded as log threshold sensitivity versus weighted eccentricity, the weighting function having been derived from previous studies. These points will be reduced to a measure of the mean slope, which will be normalized to the results from the normally sighted subjects.

Contrast sensitivity at five spatial frequencies will be determined through a two-alternative forced choice procedure at a distance of 1.5 meters, using the Nicolet Optronics CS 2000 system. The field tested will subtend 8.6 by 10.6 degrees visual angle, and the space averaged luminance will be 100 cd/m². Symbol identification will be assessed using a four-alternative forced choice procedure to determine the probability of correct identification of four non-verbal symbols at each of seven sizes and two contrast levels. The test distance will be 1.5 meters

and the background luminance will be 100 cd/m².

The results of all tests will be checked for multiple correlations and colinearities, and models of symbol

identification performance will be developed using the results of the clinical tests as predictor variables.

Low Vision Reading: Optimizing Visuo-Motor Performance

George T. Timberlake

Eye Research Institute of Retina Foundation, Boston, MA 02114

Sponsor: National Eye Institute

Purpose—A significant obstacle to the independence and rehabilitation of the visually handicapped is a loss of their ability to read text. Despite this, little is known about the retinal loci and retinal movements used in reading by our increasing population of elderly patients with macular disease.

Scanning laser ophthalmoscopy provides a unique means of obtaining this data since it permits determination of the retinal loci of visual defects, measurement of visual acuity profiles on the retina, and direct observation of retinal movements during reading. We propose to use scanning laser ophthalmos-

copy to obtain this information in a study: 1) to determine optimal retinal loci and movements for individuals with macular disease; 2) to analyze which combinations of text orientation, size, and movement are most effective for particular scotomata size and locations; and, 3) to investigate procedures for training patients to optimize residual retinal function. Additional long-term benefits from this study include the development of more efficient low vision aids and more effective text displays for the visually impaired.

Visual Tests for Patients with Central Scotoma

Rockefeller S. Young

Texas Tech University, Health Sciences Center, Lubbock, TX 79430

Sponsor: National Eye Institute

Purpose—The ultimate goal is the development of visual tests that can be used by practicing eye care specialists to evaluate the useful vision in patients with bilateral central scotoma. Patients with central scotomata, as a general rule, have adequate vision for mobility under ideal conditions. The factors that limit their residual vision include contrast and illumination levels.

The specific aims of this investigation are: 1) to determine whether the reductions in contrast sensitivity correlate with the severity of visual problems that patients experience in everyday situations; 2) to determine whether contrast sensitivity correlates better with the patients' experience than other visual measures, such as the size of the patients' scotoma;

and, 3) to determine whether the measurement of vision at different illumination levels contributes to the evaluation of the patients' ability to function in their environment.

Progress—The approach for evaluating the relative merits of different visual tests and illumination levels uses a multiple regression analysis. The patients' ability to function in everyday situations will be assessed by asking the patients to estimate (on a scale of 1 to 10) the degree of visual difficulty that they experience. A multiple regression (R²) value will be computed between the visual measures, such as contrast sensitivity, and the questionnaire responses.

Expansion and Enhancement of the National Blindness and Low Vision Database

J. Martin Giesen, Ph.D.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University,
Mississippi State, MS 39762

Sponsor: National Institute on Disability and Rehabilitation Research and Mississippi State University

Purpose—The purpose of this project is (a) to expand the MSU RRTC National Blindness and Low Vision (NBLV) Database to approximately 1000 cases by adding recently closed cases and (b) to increase the national representativeness of the NBLV Database by expanding the geographic range of the states sampled. The NBLV Database is designed to provide extensive information abstracted directly from case files by a trained data collection team. The information on each case includes case service and demographic data such as that from the R-300 or R-911 form, running record information such as multiple disabilities, use of aids, mobility training, occupational history, facility and counselor proximities, and specific service expenditures and results in over 250 client variables for each case. The information can thus be analyzed in various ways to provide extensive descriptive information on client characteristics and service delivery patterns, and can be used to determine what factors and activities of state and private vocational rehabilitation agencies contribute most to the enhancement of employment outcomes of blind and visually impaired individuals,

as well as early prognostication of client outcome. The increased sample size will ensure that all statistical estimates will be more accurate than with a smaller sample. Also, more varied and larger special population subsamples will be available for statistical analysis. This specific project increases the database by adding proportional quota sampled cases from the states of New Jersey for FY's 1984, 1985, and 1986; and from Arizona, Mississippi, and Washington for FY's 1985 and 1986.

Progress—Site visits for data collection have been completed. Coding, cross-checking, supplemental coding of jobs and disabilities, unemployment rates, etc., and data entry tasks are in progress preliminary to entry of the new data into the NBLV database. Program documentation will be updated to accommodate the new cases. Summary frequencies and descriptive statistics will be produced to describe the database. A brief annotated index report and descriptive statistics in computer printout form will be available for dissemination.

An Optimal, Inexpensive Text Entry System for the Orthopedically and Neurologically Disabled

Cheryl Goodenough-Trepagnier, Ph.D., and Stephen Levine, Ph.D.

New England Medical Center, Boston, MA 02111

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—The purpose of this project is to devise software to support design of user-device interfaces to optimize text-entry performance by disabled users of communication aids and computers.

Progress—Keyboard optimization has involved three approaches to the mapping of language menu items to the keyboard: 1) direct selection, i.e., assignment of each language item to a different key; 2) encoding, i.e., mapping onto fewer discrete signals than there are language items, with resultant increase in the

average length of the sequence of keys representing each item; and 3) mapping more items to fewer keys, as in number two, but requiring fewer key strikes per item, comparable to approach number one. This last approach, which has been the focus of recent work, utilizes additional software developed to disambiguate the output of ambiguous keyboards.

Optimization in all three cases makes use of models of motor performance derived from application of the Tufts-MIT Prescription Guide, devel-

oped by the P.I. and Dr. Michael J. Rosen at New England Medical Center and the Massachusetts Institute of Technology. In the case of approach number three, the optimization software predicts the error rate that each character-to-key assignment pattern will yield, and attempts to produce assignment patterns that minimize this rate. Investigation of the relationship between error rate (i.e., residual ambiguity) and number of keys is in progress.

Preliminary Results—Ambiguous keyboards have been shown to be potentially significantly more effective in increasing communication rate. This gain appears to be achievable without increasing mental load relative to direct selection keyboards.

Future Plans/Implications—Research is being planned

on determining optimal parameters of an ambiguous keyboard text entry system, including utilizing both single-strike and coding, investigation of editing procedures, and a range of language statistics bases.

Publications Resulting from This Research

Adaptive Technique for Customized Interface Design with Application to Nonvocal Communication. Levine SH, Goodenough-Trepagnier C, Rosen MJ, Getschow CO, *Proceedings of the 9th Annual RESNA Conference*, 399-401, Minneapolis, MN, June 1986.

Multi-Character Key Text Entry Using Computer Disambiguation. Levine SH, Goodenough-Trepagnier C, Getschow CO, Minneman SL, *Proceedings of the 10th Annual RESNA Conference*, 177-179, San Jose, CA, June 1987.

Computer Disambiguation of Multi-Character Key Text Entry: An Adaptive Design Approach. Levine SH, Minneman SL, Getschow CO, Goodenough-Trepagnier C, Rosen MJ, presented at Conference on Systems, Man & Cybernetics, 1986.

Time Use and Resource Allocations of People with Visual Disabilities: Assessment Instrumentation

William H. Graves, Ed.D.; Corinne Kirchner, Ph.D.; Kathy Nelson, M.A.; Shelly Marmion, Ph.D.
Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University,
Mississippi State, MS 39762; American Foundation for the Blind, Social Research Department,
New York, NY 10011

Sponsor: *National Institute on Disability and Rehabilitation Research; American Foundation for the Blind; Mississippi State University*

Purpose—The aim of this project is the development of instrumentation and sampling methodology to assess the way that people with visual disabilities use time and how they allocate their resources.

Progress—Reviews of time use and resource allocation literature have been completed. A series of four telephone survey instruments has been developed to elicit the following information from blind and visually impaired persons: a) educational background; b) employment history; c) visual disability; d) reading; e) mobility; f) job modifications; g) living arrangements; and, h) income and expenditures.

The time diary methodology will be employed to assess time use information. Sighted, nondisabled cohorts identified by the blind and visually impaired individuals surveyed will provide comparison data. A sample of 120 (60 blind and visually impaired; 60 sighted, nondisabled) persons will be surveyed in three telephone interviews to evaluate the instrumentation and the methodology.

Future Plans—Pending the outcome of the evaluation of the telephone survey instruments and research methodology, a larger survey of blind and visually impaired persons will be conducted in 1988.

Development and Validation of a Work Environment Visual Demands (WEVD) Protocol

William H. Graves, Ed.D.; B. J. Maxson, M.Ed.; C. McCaa, M.D., Ph.D.; H. Takacs, Ph.D.; J. Adkisson, M.S.; G. Smith, M.S.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: National Institute on Disability and Rehabilitation Research; Mississippi State University

Purpose—The purpose of this study was the development of procedures to analyze the visual demands of a job held or desired by a visually impaired person. The information may be used by eyecare professionals in prescription of low vision aids which will facilitate performance of job tasks or in the modification of visual tasks in the job setting.

Progress—From a pool of patients referred to the Low Vision Clinic at the University of Mississippi Medical Center, 30 subjects were randomly assigned to experimental and control groups. The job tasks required by the employment position held by each subject were analyzed, and on-the-job comfort level was assessed. For the experimental group, the Low Vision Rehabilitation Team reviewed the results of the Work Environment Visual Characteristics Protocol prior to the low vision examination (prescription, fitting, and instruction). The control group received the same range of services as the experimental group; however, the Low Vision Rehabilitation Team did not have the WEVD information from this group. Follow-ups were conducted at six-month intervals.

Results—A. *Work Environment Visual Characteristics Protocol*. The WEVD was developed. It provides for the assessment of the jobs performed by the visually impaired person in terms of action, purpose, time present at activity, footcandles observed, IES illuminance category as well as other characteristics of the work environment. B. *Work Environment Visual Demands Protocol Software*. The WEVD (version 1.0) program is designed for the IBM-PC with 128K and an Epson FX-80, IBM Quietwriter, or a compatible printer connected to the line printer port 1. The user-friendly software produces as output a report generated for the low vision rehabilitation team. C. *WEVD Evaluation Results*. The experimental group was found to report greater frequency of use of their low vision aids on the job and higher levels of comfort using the low vision aids on the job than the control group. The experimental group was found to need significantly fewer follow-up visits to the low vision clinic than the control group. No significant between-group differences were found for the other dependent measures.

A Robotic Hand Communication Aid for the Deaf-Blind

David L. Jaffe, M.S.E., and Deborah Gilden, Ph.D.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: National Institute on Disability and Rehabilitation Research; VA Rehabilitation Research and Development Center Core Funds; The Smith-Kettlewell Eye Research Foundation

Purpose—People who are both deaf and blind experience extreme social and informational isolation. Those deaf-blind individuals who use a tactile version of fingerspelling and/or sign language to “converse” with others enjoy some relief from this isolation. This tactile method is far from ideal, however, as it restricts interaction only with others who are both knowledgeable in sign language and are willing to engage in this “hands-on-hands”

communication technique. The problem is further exacerbated by the fatigue caused by this system of information exchange.

A potential solution to this problem is offered by “Dexter,” a computer-based pneumatically-powered, electro-mechanical fingerspelling hand. Dexter enables a deaf-blind user to receive tactile messages from the mechanical hand in response to keyboard input during person-to-person communication, as

well as gain access to local and remote computers and the information they contain.

Progress—A common communication technique used with and among deaf-blind people is simply a combined, hands-on version of fingerspelling and/or sign language. Instead of receiving communication visually as deaf people do, the deaf-blind person's hand (or hands) remain in contact with the hand (or hands) of the person who is fingerspelling or signing. Many of the motions present in sign language, where both hands and arms are employed to convey whole words and phrases cannot be employed in the tactile communication mode required by a deaf-blind individual. Instead, each word to be sent is typically spelled out, one letter at a time with the fingerspelling technique. Although many Usher's Syndrome patients can speak intelligibly or use sign language, others require a "hands-on" system for expressive communication.

The Rehabilitation Engineering Center of The Smith-Kettlewell Eye Research Foundation sponsored a class project conducted by four graduate students in the Department of Mechanical Engineering at Stanford University to design and fabricate a state-of-the-art fingerspelling hand. A major goal was to develop a system with controlled timing and easily modifiable finger positions. These qualities were realized in the completed project—a new robotic fingerspelling hand named "Dexter."

Dexter looks like a mechanical version of a rather large human hand projecting vertically out of a box. The four machined aluminum fingers and a thumb are joined together at a palm. All digits operate independently of each other and have a range of motion comparable to human fingers. The thumb is jointed so as to allow it to both sweep across the palm as well as move in a plane perpendicular to it. A pneumatic rotary actuator allows the palm to pivot in a rotary fashion around a vertical steel rod much the way a human hand can pivot from the wrist—except that a full 180 degrees can be achieved by Dexter.

All finger and thumb motions are actuated by drive cables. Pneumatic cylinders pull these cables, which flex the individual fingers and thumb, while spring-driven return cables open the finger joints to the extended position. The cylinders, in turn, are activated by air pressure directed through electrically controlled valves. These valves are controlled

by a microcomputer system. The actuating equipment and valving are housed in two separate assemblies below the hand.

In summary, the microcomputer and associated software control the opening and closing of a bank of valves which direct air pressure to specific pneumatic cylinders which pull on the drive cables which are the "tendons" of the fingers. As a message is typed on a keyboard (an Epson HX-20), each letter's ASCII value is used by the software as a pointer into an array of stored valve control values. Since 22 valves are controlled, three bytes are required to specify the state of each valve (open or closed). Two to six of these valve operations, each separated by a programmed pause, are needed to specify the finger movements corresponding to a single letter. Presently, the hand can produce approximately two letters per second, starting from and returning to a partially flexed neutral position.

Although the mechanical hand cannot exactly mimic the human hand in fingerspelling all the letters (such as the special wrist and arm motions required in J and Z), the fact that Dexter always produces the same motions for a given letter is an important factor in "understanding" its actions.

Preliminary Results—Deaf-blind clients of Lions Blind Center (Oakland, CA) served as subjects for the initial testing of Dexter. They were able to identify most of the letters presented by the robotic hand without any instructions, and in less than an hour were correctly interpreting sentences. Equally important was their positive emotional reaction to the hand. They seemed to really enjoy using it and to be intrigued by its novelty. There were no negative comments made concerning its mechanical nature or any other aspect of the system.

Future Plans/Implications—Additional testing will be conducted on the ability of deaf-blind people to use the robotic hand for extended periods of time, as well as on determining optimal configurations for the letters, and optimum rate of letter presentation. The possibility of modifying the one-hand manual alphabet to require only the thumb and first two fingers will also be investigated. Since the last two fingers are redundant for most letters of the manual alphabet, this may be a reasonable approach to reducing the size, weight, complexity, and expense of the system. In addition, it would make Dexter

more like typical robotic hands (i.e., those for manipulation of physical objects), which generally consist of three digits.

In the next software design iteration, a finger-position editing program will be written. This program will permit the interactive formation of letter-pair transitions. The valve control information resulting from this phase will be incorporated into the next evaluation of Dexter. The future implementation of a full 26 by 26 matrix of possible letter-pair transitions would eliminate the need for the neutral position and produce more natural fingerspelling. A faster and more intelligible fingerspelling device is anticipated.

Further test results will dictate the details of the hand positions for the various letter pairs and the rate of presentation. Modifications of the system to decrease its size and increase its portability will include replacing the pneumatic structure with stepper motors or some other efficient system.

Dexter is intended to serve deaf-blind users as a complete receptive communication system, not just a means of receiving information in face-to-face situations. Its ability to respond to computer input means it can be interfaced to a TDD to provide deaf-blind people with telephone communication. It can also be connected to computers to provide improved vocational and avocational potential to the deaf-blind community.

Publications Resulting from This Research

Dexter—A Helping Hand for Communicating with the Deaf-Blind. Gilden D, Jaffe DL, *Proceedings of the Ninth Annual Conference on Rehabilitation Technology* 6:49-51, Minneapolis, MN, June 1986.

A Robotic Hand as a Communication Aid for the Deaf-Blind. Gilden D, *Proceedings of the Twentieth Hawaii International Conference on System Sciences*, 1987.

A Robotic Hand Communication Aid for the Deaf-Blind. Gilden D, Jaffe DL, *SOMA* (in press).

The Evaluation of Low Vision Aids and Prediction of Visual Performance

Milton Katz, O.D.; Dean Yager, Ph.D.; Alan Lewis, Ph.D.; Aries Ardit, Ph.D.

State University of New York, State College of Optometry, New York, NY 10010

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The aim of this project is to determine figures of merit for low vision aids based on their modulation transfer functions (MTF) and other characteristics that may be correlated with vision, specifically, visual acuity and contrast sensitivity, through the aid. Coherent (aerial) image-forming low vision aids, such as telescopes and telemicroscopes, will be extensively evaluated. Their MTF's will be measured on and off-axis, through focus, and in sagittal and tangential orientations. In addition, we will completely measure their paraxial properties. Aids will be classified according to optical quality. Diffraction limited aids and aids with MTF's that are characteristically degraded at high, low, or all spatial frequencies, will be selected for the vision tests.

The contrast sensitivity functions and visual acuities of normal and low vision subjects, classified according to refraction optics defects or retinal and neural dysfunctions, will be measured with the selected aids. The experimental plan will enable us to systematically investigate vision through aids under controlled optical conditions of aid coupled

to eye. These conditions will range from diffraction limited to highly aberrated. The effect of pupil size on the aberrated systems will be studied.

Since the modulation transfer function measurements yield very large amounts of data, the analysis will concentrate on determining rather simple (unitary) figures of merit that correlate with the effect that the aid produces on contrast sensitivity functions measured through the aids. The long range goals of this research are to predict the interaction of vision with optical aids and to develop standards of optical performance for aids.

Progress—Optical bench tests and modulation transfer function measurements on more than 200 devices have been completed. Contrast sensitivity measurements are in progress.

Results—Angular magnification, resolving power, astigmatism, field of view, eye relief, and light transmittance of 157 low power telescopes comprising 25 models from seven manufacturers were meas-

ured. Roof-prism Keplerian telescopes provided about one-half the resolution, 30 percent lower transmittance and more objectionable image flare than Galilean designs. The roof-prism was responsible for producing overlapping doubled images that appeared astigmatic-like. The prism further compromised rotational symmetry by deviating the image in a direction along the roof edge. The Keplerian telescopes, however, had about twice the field of view of the Galilean telescopes. Notably, several Keplerian telescope models from different suppliers

were found to be optically identical, although they varied 50-100 percent in price.

Future Plans/Implications—To complete contrast sensitivity measurements and publish results on the interaction of vision through low vision devices.

Publications Resulting from This Research

Optical Properties of Low Vision Telescopes. Katz M, Citek K, Price I, *Journal of the American Optometric Association*, 58:320-321, 1987.

Sensory Aid Technology: A Career Development Intervention Strategy for Blind and Visually Impaired Persons

S. Marmion, Ph.D.; Lynn W. McBroom, M.A.; M. Haucke, M.S.; R. Jackson, M.S.
Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University,
Mississippi State, MS 39762

Sponsor: *National Institute on Disability and Rehabilitation Research; Mississippi State University*

Purpose—The purpose of this study was to determine the effects of the use of sensory aid technology on the employability and career development of blind and visually impaired persons. "Sensory aids" refers to any specially adapted electronic or mechanical device used by a visually impaired person to replace sensory information lost through the effects of visual impairment. The output of these devices is usually in a tactile, auditory, or enhanced visual mode. The study explores the types of sensory aids being provided, the resources used to provide them, and the effects of their provision on various aspects of employability and career development.

Progress—A survey instrument was sent to a representative sample of rehabilitation counselors in both public and private agencies; 91 completed surveys were returned, from which the following results were obtained. Counselors were asked to describe their background and training, their caseloads, and certain agency characteristics. A wide variety of descriptions were obtained on all of these dimensions. They also gave information concerning the number of clients in their caseloads to whom sensory aids were provided, number of aids provided, types of aids, and the sources of funding for these aids. Correlations were found to exist between such "aid" variables and characteristics of the counselors and agencies.

Counselors also provided detailed background descriptions for a randomly selected subset of clients to whom a sensory aid had been provided, and assessed the extent to which the aid had impacted on eleven aspects of the client's career development. Sixty-seven males and 62 females ranging in age from 17 to 79 were described. About half of this sample were congenitally impaired; 75 percent had a single impairment; ten percent were hearing impaired; 88 percent were legally blind. These clients differed widely in terms of educational and employment backgrounds, but on average were better educated and/or more skilled than the norm for rehabilitation clients.

Preliminary Results—Counselor's impact assessments indicated that in general, the overall impact of career development was greater for younger clients, non-white clients, those with earlier onset of disability, those with a visual field loss, and non-homemakers. The aspect of career development which was impacted most by the receipt of a sensory aid was "performing a job satisfactorily," followed by subsequent aspects of career development such as economic independence, skill enhancement, and job advancement.

Sensory aids were categorized according to their modality of output (visual, auditory, tactile, and computer/misc.), and their presumed function (read-

ing, communication, mobility, math, living skills, work skills, and computer/misc.). The greater percentage of aids provided were visual in output, followed by the computer category. The most common function for aids was reading, followed by computer usage and then math.

Chi squares and related statistics indicated that relationships exist between aid categories and the extent of impact on the 11 different aspects of career development, and that these patterns of benefit differed somewhat for congenitally blind persons

and for the adventitiously impaired. Uncertainty coefficients were computed to determine that the functional category of an aid was more predictive of impact for most of the 11 aspects of career development than was the modality of the aid. Results are discussed in terms of implications for policy and practice within rehabilitation.

Copies of the technical report and an executive summary may be obtained from the Rehabilitation Research and Training Center.

Learning Styles and Effective Teaching Technologies for Enhancing the Employment of Deaf-Blind Youth

B.J. Maxson, M.Ed.; S.L. Marmion, Ph.D.; A.M. Lamb, Ed.D.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: National Institute on Disability and Rehabilitation Research; Mississippi State University

Purpose—This field-based project is attempting to identify and evaluate instructional technologies which take into account the learning style or approach of individual deaf-blind youth and which facilitate the acquisition of independent living, community living, and vocational skills by multiply impaired deaf-blind youth.

Progress—Initial phases of the project consisted of: 1) the identification, compilation, and review of existing literature on both "learning styles" and "teaching technologies" relevant to deaf-blind education, and 2) surveying of special educators and instructional personnel of deaf-blind students about their methods and resources for assessing students' learning styles and for determining effective teaching techniques in a variety of task areas such as perception, memory, concept formation, and problem solving. Results of these two subprojects will be available in technical reports from the RRTC/BLV in the near future.

Preliminary Results—The current phase of this 3-year project involves a multi-site qualitative investigation of programs which have gained national recognition for their high success rates of vocational placement and instructional programs. Aspects of each program to be explored include: 1) the interaction between teacher and student; 2) the program-

matic organization of the program; 3) the overall characteristics of the students in the program; 4) the instructional and personality style of the teachers; 5) the participation of families; 6) the retention and reinforcement strategies involved in the program; and, 7) administrative and community support. The investigation will include both higher functioning deaf-blind students (such as those with Usher's Syndrome) and more severely involved multiply handicapped students (such as the Rubella student). Instructional observations will focus on a variety of skill areas, including the four cognitive domain areas mentioned above.

Future Plans—The four exemplary programs to be studied are the Helen Keller School at the Alabama Institute for Deaf and Blind in Talladega; the Helen Keller National Center for Deaf-Blind Youth and Adults in Sands Point, NY; Project Advance of the Perkins School for the Blind in Boston, MA, and the Texas Educational Service Center, Region XX Program in San Antonio, TX.

The project team has made arrangements to spend two weeks at each facility observing, interviewing and documenting the instructional and learning aspects of the program. The data will be compiled and compared to determine whether there are common characteristics or aspects of these exemplary programs which may be of value to other programs

concerned with developing effective instructional programs for deaf-blind youth in transition.

All site visits and an initial field test at Ellisville State School in Ellisville, MS are scheduled between

June, 1987 and February, 1988. Data analysis will be ongoing and is scheduled to be completed by March, 1988. A technical report on this subproject will be available in April, 1988.

Identification of Job Tasks and Management Practices Performed by Blind and Visually Impaired Persons in the Operation of the Business Enterprise Program

John H. Maxson, M.S.; C.S. Chen, Ph.D.; Shelly Marmion, Ph.D.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute on Disability and Rehabilitation Research; Mississippi State University*

Purpose—The Randolph-Sheppard Act of 1936 (as amended) authorizes business programs operated by blind or visually impaired persons licensed by state agencies. This study addresses 1) the need to identify those job related duties actually performed by licensed business operators under this program, and 2) a review of existing training opportunities for licensed business operators through state licensing agencies. The results of the research project should provide state licensing agencies with information to assist in the design of upward mobility training programs for blind and severely visually impaired businessmen and women operating programs under the Randolph-Sheppard authority.

Progress—Following literature review, instrumen-

tation development and pilot testing, a telephone survey was conducted. Blind business operators in cafeteria locations, snack bar and other locations and in vending facility locations were asked 71 questions related to the operation of their business. Participants were licensed operators from five states in five different ED Federal Regions, and represented approximately 8 percent of all blind businessmen and women in the U.S. Participant states have submitted their training program curricula for review. All data and information is being coded for computer entry.

Results—Results from this study, a technical report and monograph, will be available after April 1, 1988.

Identification of Work Assessment Technology Needs

Lynn W. McBroom, M.A.; William H. Graves, Ed.D.; John Seaman, M.A.; Randy Elston, Ed.D.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute on Disability and Rehabilitation Research; Mississippi State University*

Purpose—The purpose of this project is to locate and describe currently available work assessment technologies which can be reliably and validly used in their present formats with blind and visually impaired persons. Recommendations will also be made to users and manufacturers on how existing work assessment devices can be modified to meet the needs of rehabilitation and educational professionals. Needs for norm development and reliability and validity studies will be identified. Career options for blind and visually impaired persons for which work assessment technology is not available and

specific career options for which there is a need for work assessment technologies will be outlined.

Progress—Research literature, work assessment manuals, and other manufacturer-supplied information was reviewed and organized to identify any reliability and validity studies available on samples of blind and visually impaired persons. The statistical results and other information about the work assessment devices were entered into a computerized data bank for rapid retrieval and comparison among the various assessment systems. A draft

report addressing the five issues outlined in the Purpose section (paragraph 5) will be circulated among ten experts in the subject area. These ten people will be asked to review and critique the draft report, offer suggestions for revisions, assist in identifying career options for blind and visually impaired persons for which there is not appropriate

work assessment technology, and identify career options for which work assessment technologies are needed.

Results—Results from this study, a technical report and monograph, will be available after January, 1988.

Identification and Classification of the Career Transition Problems of Blind and Visually Impaired Persons Employed as Professionals, Managers, or Technicians

Lynn W. McBroom, M.A., and Mark Haucke, M.A.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute on Disability and Rehabilitation Research; Mississippi State University*

Purpose—The purpose of this project is to describe the career phenomena associated with visually impaired people and to more specifically explain the relationship between disabilities and career attitudes, abilities, events, and outcomes. By identifying and classifying the career development problems, a taxonomy will be formulated to describe the range of career development problems with which visually impaired persons must cope during career development stages.

Progress—Following a literature review, a taxonomy was developed describing the difficulties blind and

visually impaired individuals have encountered in their professional employment. A questionnaire is being revised and a sample of 200 blind and visually impaired adults who have been employed in some types of professional jobs is being readied for a telephone interview. Statistical analyses from this questionnaire will later be compared with intervention strategies used in career development transition problems.

Results—Results from this study, a technical report and monograph, will be available after January, 1988.

Modification and Adaptation of the Vocational Education Readiness Test for Blind/Severely Visually Impaired Individuals

Lynn W. McBroom, M.A.; John Seaman, M.A.; Sam Chen, Ph.D.; Steven Machalow, Ph.D.; Vicky Robbins, B.S.

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

Sponsor: *National Institute on Disability and Rehabilitation Research; Mississippi State University*

Purpose—The purpose of this project is to determine whether each of the Vocational Education Readiness Test (VERT) adapted for blind and visually impaired persons is an appropriate assessment tool for determining the aptitude of these persons to enter vocational education programs in Auto Mechanics, Basic Wiring, Quantity Foods, and Industrial Sewing.

Progress—Randomly selected subjects for the visually impaired clients and work force of five work

sites and rehabilitation centers were administered the revised work samples. Demographic and visual information on these subjects were collected. The work samples were administered in a test-retest format and pertinent work or test data collected for reliability and validity analysis.

Results—A technical report and work samples were published in August, 1986. Reliability and validity were calculated for each task within the four work samples. Descriptions of the norm groups and per-

centile charts were provided for each work sample.

The Auto Mechanics, Basic Wiring, and Quantity Foods work samples are reliable and valid measures for evaluating a client's readiness for entry into a

vocational education training program. The Industrial Sewing work sample should not be used for this same purpose.

Cutaneous Pattern Perception

James C. Craig

Department of Psychology, Indiana University, Bloomington, IN 47405

Sponsor: National Institutes of Health

Purpose—The proposed research will investigate the perception of tactile patterns by human subjects. The tactile patterns will be generated on arrays of stimulators that fit against the subject's fingertips. Each array consists of 144 stimulators arranged in a matrix 6 columns by 24 rows. Sets of patterns differing along such dimensions as location, intensity, number of line segments, and so forth will be generated and presented to subjects. Response measures will include identification, discrimination, reaction time, and pattern matching.

Three aspects of tactile pattern perception will be examined: masking, interactions among multiple sites of stimulation, and the role of experience. A temporal masking paradigm will be used to see how the perception of tactile patterns is interfered with by tactile maskers and how the nature of the interference changes with changes in the type of masker and in the temporal separation between target and masker. In the studies of interaction among multiple sites, patterns will be presented to as many as three sites on the fingertips and palm. This paradigm will

be used to assess the role of attention in tactile information processing. The role of short-term experience will be examined by measuring changes in pattern perception as subjects learn to identify and discriminate tactile patterns. The effect of long-term experience will be evaluated by comparing the performance of groups of subjects who differ in the amount and nature of their experience with complex tactile patterns. One group will be Optacon users, blind individuals who can read by means of a tactile array. The other groups will be blind individuals without Optacon experience and several groups of sighted subjects with varying amounts of tactile experience.

The proposed research will be concerned with drawing parallels between tactile processing and visual and auditory processing, with developing measures relevant to understanding the neural coding of tactile patterns, and with improving cutaneous communication systems for the blind, deaf, and deaf-blind.

Normative Data for Assessing the Manual Dexterity of Visually Handicapped Adults in Vocational Rehabilitation

M. J. Tobin and R. Greenhalgh

Department of Special Education, University of Birmingham, Birmingham B29 7JE, UK

Sponsor: Research Centre for the Education of the Visually Handicapped

Progress—Nine hundred and ninety-one newly blinded and visually handicapped adults were tested with the Purdue Pegboard test of manual dexterity while they were undergoing vocational rehabilitation. Normative data were derived to enable comparisons to

be made among various subgroups of the population on the basis of degree of residual vision, which together with the gender of the subjects is shown to be a significant determining variable. The results are also discussed in terms of the magnitude of the

disparity between the performance of the visually impaired and the fully sighted adult subjects on whom the test was originally standardized.

Publication Resulting from This Research

Normative Data for Assessing the Manual Dexterity of Visually Handicapped Adults in Vocational Rehabilitation. Tobin MJ, Greenhalgh R, *Journal of Occupational Psychology*, The British Psychological Society, 60:73-80, 1987.

Sensory Aids for the Blind and Visually Impaired

Arthur Jampolsky, M.D.; John Brabyn, Ph.D.; Deborah Gilden, Ph.D.

The Smith-Kettlewell Eye Research Foundation Rehabilitation Engineering Center, San Francisco, CA 94115

Sponsor: *The Smith-Kettlewell Eye Research Foundation; National Institute on Disability and Rehabilitation Research*

The following are summaries of the past year's projects of the Smith-Kettlewell Rehabilitation En-

gineering Center, with support from the National Institute on Disability and Rehabilitation Research.

An Improved Volatile Braille Display

Purpose—The Volatile Braille Display, consisting of a row of braille characters which can be manipulated electronically, is generally acknowledged to be among the most desirable forms of access to electronic data for blind individuals. To date, commercially available versions of these devices have often suffered from high expense or reliability problems. Consequently, the Smith-Kettlewell REC has developed an innovative concept for a new generation of refreshable braille displays, using inexpensive electromagnetic technology and elimination of most moving parts through a special proprietary

design.

Progress—This year, attention has focused on the development of a 20-cell prototype of the device. Initial tests of the completed mechanical unit revealed that the braille dots were prone to sticking in the down position, and a number of other problems were identified. A new 3-cell prototype incorporating the design improvements necessary to overcome these has now been built and in initial testing it appears to offer successful operation along with greater simplicity of design.

Universal Job Instrumentation System

Purpose—The Smith-Kettlewell Flexi-Meter is the universal measuring instrument which derives its philosophy from the original Talking Pressure Gauge completed earlier. It is intended that the current design will be the basis for a relatively economical and reproducible computer-based measuring instrument which will be easily programmable to fit a wide variety of occupational needs. Activity in this project has been proceeding toward the fabrication and testing of the first prototype.

Progress—Our experience with the microcomputer-based Talking Pressure Gauge System (now in use

by the refrigeration repair person who originally requested it) has proven valuable in refining our approach towards the more flexible design now being undertaken. The Pressure Gauge System, which allows the operator to measure the high-pressure, vacuum, and low-pressure ranges necessary in the testing and recharging of refrigeration and air conditioning equipment, was originally delivered in October of 1985—and has been tested and returned for minor modifications and repairs several times during this year. The device is now providing reliable service in the user's repair shop, allowing the operator to complete his work independently and much

more quickly than would be the case if he had to ask help of sighted technicians who are less experienced than this blind worker.

A questionnaire describing the main features of the proposed design and requesting four categories of information was sent to one hundred recipients, taken from the mailing list of those who receive our Annual Reports. Besides the vocational rehabilitation services of all fifty states, other educational centers and training programs were targeted. The responses were used to finalize the specifications for the first prototype.

Specialized Vocational Aids and Devices

Progress—Many specialized vocational sensory aids have been developed during the year, including the following:

Auditory Breakout Boxes. After receiving requests from such agencies as the Kentucky Bureau for the Blind, the Veterans Administration Western Blind Rehabilitation Center, and the National Federation of the Blind's Committee on Research and Development, we developed a prototype Auditory Breakout Box to simplify the interfacing of computers and peripherals by blind users. Sighted individuals have access to breakout boxes which can be connected between the computer input/output port and a peripheral. Each input signal line can be connected, through the use of jumpers, to any output line, and the device will indicate (through activation of LEDs) when the correct connections have been made. To make this ability available to blind individuals, we have developed an Auditory Breakout Box that provides a similar convenient means of trying different connection combinations, and utilizes a tonal sound coding system to indicate whether any selected line is grounded, high, low, or open.

This device has been successfully field-tested by several users. As a result of these field evaluations, it was found that there were possible improvements to be made on the jumper connection panel. One user complained that the protruding pins tended to retract into the panel when fitted with jumper wires. A temporary solution to this problem is to deposit a bead of epoxy over the connections on the panel's underside. Better quality pin "headers" are available which would constitute a permanent solution.

Preliminary Results—As a result of the evaluation of our refrigeration pressure gauge system, the preliminary results of our market survey, research into available equipment and components, and intensive design discussions within our staff and with other experts in hardware and software design, the specifications of the Flexi-Meter were delineated. In general, both the input and the output systems are expandable to add additional functions (such as those which were required by the user of the refrigeration pressure gauge system). The first prototype is now complete and is being tested prior to field evaluation.

The amphenol sockets which are used on the jumper wires loosen up with constant use. While these can be tightened with needle-nosed pliers, a better solution would be to find new connectors. Several options for the production of this device are currently being explored.

Computer Interface Aids. To enhance computer accessibility for the blind, an auditory data-flow indicator was developed at the request of the Kentucky Bureau for the Blind. They have now made it commercially available for \$17 as the "Tweedle Dump." This device was designed to provide an indication to the blind user when data transfer is in progress in an RS-232 serial interface, aiding him in knowing whether the interface to printers and other peripherals is operating normally and when the computer is free to receive other input. It is especially useful with modem operations in alerting the user when a long data transmission has finished. The device consists of a simple audio transducer built into a standard interface cable, and is driven directly from the data signals.

Computerized Court Stenographic Equipment—Adapting the Position of Court Reporting for the Blind. The Rehabilitation Engineering Center was approached by the Sensory Aids Foundation (SAF) to determine whether suitable technology can be found or developed to enable several blind clients who are currently undergoing training as court stenographers to obtain employment in actual courtroom settings in this field. Many more blind individuals would be interested in this vocation if suitable means were available to accomplish all of the

sub-tasks required of court stenographers. Our findings from these investigations should have a practical impact on others by providing a summary of the

“state of the art” and the available practical options—most of which we or members of our collaborative team have tested or observed.

The Note-a-Braille

Purpose—The Smith-Kettlewell Note-a-Braille is a portable electronic note-taking device with a braille keyboard for input, a memory capable of storing about eight pages of braille text, and a means of sending the stored notes in ASCII format to a receiving device (computer, printer, synthetic speech device, etc.). Once in the computer, the text can be edited or otherwise manipulated as required.

The philosophy of the Note-a-Braille is to allow rapid keying-in of notes from meetings, classes, etc., with little heed being paid to errors. The unit can then be taken home for accessing or editing the notes on one of the accessible computer systems now being used by an increasing number of blind individuals. By taking advantage of this mode of operation, the user of the inexpensive portable device is not forced to pay for another editor or read-out system. (Concurrently with the development of the Smith-Kettlewell Note-a-Braille, the Kentucky Bureau for the Blind has recently been engaged in the development of another braille note-taking unit with a slightly different emphasis. The philosophy behind the Kentucky unit is to incorporate a speech synthesizer output and controls for text review within the unit itself, making for a more sophisticated and expensive system.) Furthermore, the compact nature of the braille keyboard as compared with a conventional “qwerty” keyboard gives the blind user an advantage over his sighted counterpart, since the braille note taker can be made considerably more compactly than any comparable device could be made for note-taking by the sighted.

Progress—During this reporting period we completed testing of the bench model Note-a-Braille, and designed, built, and tested a portable prototype.

We are now in the process of exploring a further reduction in overall size of the design, for a second model.

Another area of activity was the acquisition and evaluation of a number of parallel-to-serial converters. This type of converter is needed if the receiving computer or device does not have a parallel input port. As a result of this evaluation, we were able to specify two commercially available devices suitable, without qualification, for this function. The cost of these devices is in the \$50 to \$100 range. An additional feature of the Note-a-Braille is that besides storing entries in its memory, it also sends this data immediately to the output connector. This makes possible the use of the Note-a-Braille as a braille keyboard.

Results—The prototype unit has been used extensively by members of our staff and by blind visitors and students, and has elicited enthusiastic comments from all who have tried it. It has seen use in taking notes during several meetings, and it was used to write portions of this report. A number of requests have been received for documentation for this design—from individuals not wishing to wait until the device goes into production. Accordingly, the original design has been fully documented and published, and at least one unit has been fabricated to our plans by a blind user in England. The May 1986 issue of *Technology Update* published by the Sensory Aids Foundation described the device, and the Summer 1986 issue of *The Smith-Kettlewell Technical File* contained complete information for construction of the unit. This documentation is now available directly from the REC. Commercial production is scheduled for late 1987.

Dotless Braille Reader

Purpose—Dotless braille is a new concept and is intended for blind and deaf-blind people who are no longer able to read braille due to decreased tactile

sensitivity, as sometimes happens in those suffering from peripheral neuropathy associated with diabetic retinopathy or even from carpal tunnel syndrome.

It is based on the fact that braille is a code for reading, with raised dots being merely one of several possible methods of displaying the code.

Dotless braille is intended to be produced by a device with keys arranged like those of a braille writer; i.e., three keys for the left hand, three for the right, and a space bar, but it is designed to produce 8-dot rather than 6-dot braille. Instead of serving as a vehicle for sending information by the user's pressing the keys, however, in this system the user passively rests his fingers on the keys and "reads" via the combinations of keys which move upward from a resting point. The keys will be activated by ASCII input from a computer, or by a camera with optical character recognition capabilities, letter by letter. Each letter will be represented by the same key combinations which would be depressed to emboss that particular letter in standard braille. Favorable reactions to this concept have been obtained from rehabilitation professionals as well as blind consumers.

Progress—Research has been conducted to compare the use of dotless braille keys pressing upward against the underside of the user's fingers with their dropping down away from the user's fingers. This evaluation was conducted on a test unit we fabricated which has one upward-bound and one down-

ward-bound key. There has been a consensus among blind braille readers that the upward excursion seems to be more "intelligible." Another possible advantage of the up-moving keys is that this motion would preclude possible confusion between reading and writing in the ultimate device which could serve both functions. In other words, if downward-moving keys were used to both read and write, a user might question whether he pushed them down or the input device activated them.

Future Plans/Implications—The next dotless braille prototype unit, now completed, has the full complement of eight keys and a space bar. It will be evaluated with blind and deaf-blind subjects as a reading/communication machine.

Dotless braille is aimed at a relatively small target population, but if it proves to be useful as intended, it could have a tremendous impact on the lives of this group. Former braille users rendered functionally illiterate by peripheral neuropathy will instantly have their reading capabilities restored. The potential impact this device may have on the lives of certain deaf-blind individuals is even more dramatic, as in addition to allowing them to read again, it could restore a major input channel for communication.

Dexter: A Mechanical Hand for the Deaf-Blind

Purpose—The Smith-Kettlewell REC sponsored a rehabilitation engineering class project for four mechanical engineering graduate students at Stanford. Based on the original hand developed by the SouthWest Research Institute nearly a decade ago, the students designed and fabricated a more state-of-the-art mechanical hand which fingerspells information into the hand of a deaf-blind user. The hand ("Dexter"), completed in June 1985, is computer-controlled and keyboard-activated, and provides for input for both face-to-face and remote communication. Preliminary evaluation at the Lions Blind Center, Oakland, California, demonstrated that deaf-blind people could "read" information transmitted via Dexter.

Progress—During the past year, initial steps have been taken to simplify and refine the Dexter system. In addition, we have also undertaken development aimed at making it more portable. The large IBM computer which had been activating the hand has been replaced with a 3-lb. Epson HX-20 lap computer. Both the computer and the controller now have their own memories, and their software is called up the moment each device is turned on. It will be possible to use this as an authoring system, so that the user can specify hand shapes and speed of letter presentation as desired. Another improvement made to the Dexter system this year was the replacement of a prototype hand-wired printed circuit board with two commercially available boards which can easily be replaced as needed.

Pediatric Research

Progress—The primary goal of the Pediatric REC for the past year has been to develop, refine, and field test a method of mass screening for ocular disorders in young children and infants. To this end, we have continued engineering development of a photographic method for determining refractive error, strabismic angle and media clarity. The device we have used initially is based upon commercially available 35mm cameras and strobe flashes. We are also in the process of modifying a commercially available Polaroid camera for use as a screening device. The design we plan for the Polaroid camera is intended, with some modification, to be generally applicable to any camera with a flash unit. We have conducted several laboratory studies intended to support the practical application of the photographic screening device. A major clinical concern which we have addressed in the past year is the detection of the presence of significant astigmatic errors. We have conducted a series of bench tests which have led us to the understanding of the utility of our device for astigmatic error screening.

In our collaborative field screening programs evaluating the photographic screener, we have identified a number of infants with significant astigmatic errors and with other undetected refractive error differences between the two eyes. Several of these infants are currently wearing glasses as the result of our early detection of their eye problems. We are continuing our own demonstration mass-screening effort and will be conducting follow-up visual assessment of infants found to have significant refractive errors.

We have conducted a series of laboratory studies of the changes in the appearance of the red-reflex which is also documented by our photographic screener. We have found that most of these changes are due to reflection of light from the optic nerve head. Our clinical database is presently limited to mainly esotropic cases (eyes turned in). During the remainder of the year we will screen a group of exotropic infants and children to determine if our hypothesis regarding the imaging of the optic nerve head is correct.

Applications of Evoked Potential in Rehabilitation

Progress—Dr. Erich Sutter, of our REC staff, has carried out two projects during the past year under separate funding from the National Eye Institute and The Smith-Kettlewell Eye Research Foundation.

Vision-Based Communication Aid. The eye-gaze-directed communication system for the handicapped, based on visually evoked potentials, has seen considerable advances in its development and practical implementation. A special high-speed process board has been developed, and the use of color stimuli has been explored. Two methods of reducing noise due to muscle artifacts are being investigated, and a new method of coupling electrodes to the scalp without requiring "wet contact" is being explored. A practical prototype system has been developed for long-term evaluation in the field. It permits the user to access commercial software such as word processors, and will assist in the development of the concept towards a marketable product.

Objective Perimetry. A second project conducted by Dr. Sutter during the past year has been the

development of a novel method of visual field assessment utilizing the electroretinogram (ERG). This new concept involves the visual stimulation of 256 retinal locations simultaneously, while recording signals from a conventional ERG electrode pair on the eyeball. The technique allows objective assessment of local retinal function in recording times of approximately fifteen minutes, and shows potential for improved detection of retinal defects associated with visual disorders. Improved information of this type has the potential to make a major impact on both medical treatment and low vision rehabilitation.

Publications Resulting from This Research

Assistive Devices for the Blind and Visually Impaired. Brabyn JA, *Wiley Encyclopedia of Medical Devices and Technology* (in press).

Photographic Detection of Amblyogenic Factors. Day S, Norcia AM, *Ophthalmology* 93(1):25-28, January 1986.

Technology to Overcome Obstacles. Gilden D, *The Deaf-Blind American* 24(3):80-90, American Association of the Deaf-Blind, March 1986.

Dexter—A Helping Hand for Communicating With the Deaf-Blind. Gilden D, Jaffe D, *Proceedings, Ninth Annual*

Conference, RESNA 6:49-52, Minneapolis, MN, June 1986.
A New Device for Measurement of Visual Adaptation. Haegerstrom-Portnoy G, Adams AJ, Jampolsky A, *Proceedings, Ninth Annual Conference, RESNA 6:35-37, Minneapolis, MN, June 1986.*

Talking Signs—An Accessibility Solution for the Blind and Visually Impaired. Loughborough W, *Proceedings, 12th*

C.M.B.E.C./1st Pan-Pacific Symposium, Vancouver, BC, July 18-26, 1986.

Photorefractive with a Catadioptric Lens. Norcia AM, Zadnik K, Day S, *Acta Ophthalmologica* (in press).

Vestibulo-Ocular Reflexes of Adventitiously and Congenitally Blind Adults. Sherman KR, Keller EL, *Investigative Ophthalmology and Visual Science 27:1154-1159, 1986.*

Automatic Lens Focusing for the Visually Impaired

Paul Kalata

Department of Electrical and Computer Engineering, Drexel University, Philadelphia, PA 19104

Sponsor: U.S. Department of Education, Office of Special Education and Rehabilitation Services; National Institutes of Health

Purpose—Many visually impaired individuals use special telescopic lenses as visual aids. Focusing and refocusing these lenses due to changes in object distance not only becomes tedious and monotonous for individuals, but is difficult for the aged or multi-handicapped. This report describes the progress of an automatic lens focusing system design and development effort. The system is intended to be practical, portable, and affordable. The level of performance in terms of quickness and quality of focus is intended to be as good as that of the currently available hand-held movie/tape recorders equipped with autofocusing.

Progress—There are two autofocusing systems under investigation. They are identified by the type of sensor: 1) an active sensor using ultrasonics; and, 2) a passive sensor using an array of photo detectors.

In the ultrasonic system, the computer control and lens motor drive subsystem vary slightly depending on the front end sensor. However, they essentially perform the same relative functions. The system contains a distance measuring device, computer control, and motor drive lens systems. These three subsystems work together to provide the basic operations that a normal, healthy human vision system goes through: imaging, quality evaluation, and action to improve. The system's digital computer not only generates and processes the various signals, it also monitors all the functions and provides an overall system control.

Results—The ultrasonic type autofocusing lens system was designed and constructed. It is currently fully operational. Initially, an Apple IIe computer

with five power supplies were used to drive the autofocusing lens system. The system has been further developed and currently uses a Macintosh computer and requires only two power supplies.

The investigation of the passive array of photo detectors as a sensor for the autofocusing lens system has also made progress. A development system including sensor, interface chips, and micro-processor controller have been integrated with a telescopic lens. System focusing investigations are in progress as of this writing. Preliminary results indicate that this system works.

Future Plans—The plan is to continue working with both of the autofocusing lens systems, but with slightly different purposes in each case. The ultrasonic version will be used to evaluate system-related operations, including human/algorithm relationships. In the case of the photo array, we will seek to integrate this sensor into a fully operational system.

The reason is that the photo detector array system is the more promising in terms of performance, as well as being light in weight. We expect to be able to design and implement a realistic, portable device employing a photodetector array.

This research investigation has been aided significantly by the Pennsylvania College of Optometry. Drs. Anthony DiStefano and Richard Brilliant of the William Feinbloom Rehabilitation Center provided invaluable insight into the problem. Mr. Robert Ellis not only provided the telescopic lenses, but also personally fabricated the necessary parts to allow the motor and unique drive train to focus the lenses.

A. Blindness and Low Vision

2. Mobility Aids

Evaluation of Electronic Travel Aids (ETAs) for Visually Impaired Individuals

Bruce Blasch, Ph.D.

Veterans Administration Medical Center, Decatur, GA 30033

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This is a 2-year study of Electronic Travel Aids (ETAs) which will closely examine the performance of existing ETAs and the travel needs of visually impaired people. Although research and development of ETAs has been ongoing since World War II at a cost of millions of dollars, only four devices have made it to the production stage, with approximately 3,000-3,500 purchased (Blasch, 1985). Preliminary data indicates that visually impaired persons own nearly 1,000 of the ETAs, while the remaining 2,000-2,500 are used for training, are in stock, or have been abandoned.

The four commercially available ETAs are the Pathsounder, the Mowat Sensor, the SonicGuide, and the Laser Cane. This study will determine the strengths and weaknesses of existing ETAs, reveal which types of individuals can benefit from ETAs, and provide recommendations of performance characteristics for future ETAs. The data will answer the questions: 1) How many people are using each

device? 2) What is the profile of the visually impaired person that will most likely benefit from an ETA? 3) What are the strengths and weaknesses of the devices? 4) What situations are most appropriate for using the device? and, 5) What are the directions and needs for future ETA development?

Progress—The steps involved in this project consist of locating ETA consumers, developing the telephone interview, writing a computer program for direct data entry by the interviewer, training the interviewers, conducting the survey, and analyzing the results.

At this time, a database has been organized which contains approximately 400 names and addresses of current and former ETA users. The written survey and computer program are in the final phase of development and training of interviewers will be starting in the near future.

Clinical Application Study of Training Techniques and Devices for the Blind

William R. De l'Aune, Ph.D., and Duane R. Geruschat, Ph.D.

Eastern Blind Rehabilitation Center, Veterans Administration Medical Center, West Haven, CT 06516

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The measurement of mobility performance has been a difficult challenge to scientists. The difficulties have been caused most often by problems in determining what variables to measure (i.e., stride length, body posture, total time, straight line of travel). Previous work by the investigators has demonstrated that mobility instructors can reliably measure client performance with a behavioral checklist of critical events, such as bumping, stumbling,

or poor street crossings. This approach, while reliable, is of limited experimental or practical use as the results showed a low frequency of critical mobility events. This makes it difficult to demonstrate the effectiveness of mobility instruction. To increase the amount of obtainable data, without increasing the environmental complexity and compromising subject safety, a secondary task methodology was coupled with the checklist approach. The objective

of this study was to generate multiple performance measures for the assessment of mobility performance prior to, and following, mobility instruction.

Progress—Blind and visually impaired subjects who agreed to participate in the study were requested to complete three different experimental conditions on two separate occasions. The three conditions were: 1) seated while responding to an auditory tone; 2) walking sighted guide while responding to an auditory tone; and, 3) walking independently while responding to an auditory tone. The independent walk consisted of a 7-block route in a residential and small business environment. Each of these conditions was completed sometime during the first 10 mobility lessons (pre-test) and repeated during the last 10 mobility sessions (post-test). Therefore, each subject provided data on six separate occasions.

A hand-held Tandy PC-6 pocket scientific computer was programmed to generate a randomly timed, high pitched tone (beep). Modifications were made to the computer so that the subject would respond by squeezing the computer, which produced a response tone. The subject wore a set of Sony earphones which permitted the computer-generated and response tones to be heard in environments with ambient sounds. The computer provided data on the number of samples, the number of responses, the mean reaction time and the standard deviation.

The subjects for this experiment were veterans assigned to the Eastern Blind Rehabilitation Center in West Haven, CT. This population is primarily male, over 50 years of age, adventitiously visually-impaired, partially-sighted, and with additional physical or cognitive impairments. As of the writing of this abstract, 16 subjects have completed the experiment.

Preliminary Results—Results of the experiment at this time demonstrate that reaction time is a stable measure with test retest reliability coefficient of $r = 0.975$, $df = 14$. Additional results indicate that when walking sighted guide, a two-fold decrease in performance occurs. When required to walk independently, a four-fold decrease in performance occurs. These results are all statistically significant.

Future Plans/Implications—This study demonstrates the efficacy of the secondary task approach to describing mobility performance. This approach minimizes the need to expose subjects to difficult environments to assess critical events by increasing the complexity of the task through the introduction of the secondary measure. The results also suggest that the effectiveness of mobility instruction may be captured with this technique and can serve as one approach to documenting improvements in travel through systematic instruction.

Measuring the Mobility of Blind Travelers

Rebecca Hollyfield, Ph.D.; Sheila Courington, Ph.D.; William Fisher, M.A.
Veterans Administration Medical Center, Hines, IL 60141

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objective of this study was to create a scale for measuring the gait-related aspects of mobility: to measure these aspects and the travel activity of blind travelers before and after training; and to determine the relationship between travel activity and gait-related mobility.

Progress—Twenty subjects, half of them totally blind and half with low vision, volunteered for this training at the Hines Blind Rehabilitation Center.

Travel activities of the patients were measured using a self-report, guided interview. Each person

estimated how often they performed 19 particular activities; how often they did the activity alone; and how difficult it was to do the activity. Easiest activities involved behaviors that can be done at home or close to home. Activities that involve travel a greater distance from home and/or may require transport are more difficult. The most difficult items concern activities that may not be completely determined by travel skills, such as interest or motivation, to be involved in such activities.

The gait characteristics of each patient were assessed before and after training using a gait-

measuring system during several types of circumstances. Step length and step time were measured at each event. Step length during simple tasks is longer than when the person is doing a more difficult task; inversely, step time is shorter during simple tasks and longer when doing more difficult tasks. The ratio of step length to step time gives a measure of walking speed at each of the events measured. The walking speed data were scaled to produce an instrument that provides an overall measure of the gait-related aspects of mobility.

Results—It was hypothesized that travel activity and skills as measured by gait parameters would not be highly correlated because travel activity was thought to depend upon a number of variables such as mood,

interests, family attitudes, and cognitive skills that are not related to travel skill. The correlations between travel activity and gait parameters support this hypothesis.

Blind and low vision patients were assessed in the study and the differing effects of training on these two groups were measured. Travel activity reported by blind patients was significantly lower before training than that of low vision patients. At the end of training there was not a significant difference between them. Blind subjects did significantly poorer than low vision patients on pre-training gait measures but made a noticeable improvement as a consequence of training. The improvement did not, however, bring them up to level of the low vision patients.

Measuring the Spatial Layout Knowledge of Visually Impaired Adults

Rebecca Hollyfield, Ph.D.; Ralph Haber, Ph.D.; Lyn Haber, Ph.D.; John Trimble, Ph.D.; Charles Levine, M.A.; James Gramata, B.S.

Rehabilitation Research and Development Center, Hines Veterans Administration Hospital, Hines, IL 60141 and University of Illinois at Chicago

Sponsor: VA Rehabilitation Research and Development Service

Purpose—In order to create better aids and techniques for orientation training for visually impaired travelers, it is necessary to fully understand the spatial knowledge of these travelers. At present we do not even know much about such knowledge of sighted adults and it is not obvious how much we can generalize from the latter to the former. In particular, the three level distinction among landmark, route and global layout knowledge, while reasonable, is still unproven.

The orientation skills of visually impaired persons cannot be assessed without a reliable and valid instrument. With such an instrument we can establish the effects of both individual differences and environmental factors on the successful orientation of visually impaired travelers. Thus, goals of this project include: 1) The development of a reliable and valid response measure; and, 2) a description of the spatial representations of blind travelers at a level of detail sufficient to guide the creation of optimally compatible spatial displays and training

programs for these travelers.

Progress—The first step in this project is to establish a reliable and valid measure of spatial knowledge in both sighted and visually impaired persons. Seven such measures are being tested against each other, using a variety of psychophysical and psychometric criteria. The best measure will then be used for further studies. The measures of spatial layout are being created and tested.

We then will focus on the variables associated with various types and sizes of scenes and environments that are frequently encountered by travelers. In addition, we will assess the effects of a traveler's interactions with a scene (e.g., passive guidance versus active search), the effects of formal training in orientation and mobility skills, and the effect of specific training on spatial layout knowledge. Finally, an assessment of the effects of individual differences on spatial knowledge using a multiple regression analysis will be made.

Digital Techniques for Objective Analysis of Aural Acoustic Immittance

Larry N. Robinette, Ph.D., and David J. Thompson, Ph.D.

Audiology Research Program, William Jennings Bryan Dorn Veterans Hospital, Columbia, SC 29201

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The current one-year project concludes the evaluation and implementation of a digital (“programmable”) acoustic-immittance instrument interfaced to a personal computer (IBM).

Progress—Emphasis was on completion of research-oriented software (Summit software; BetterBASIC) to utilize the programmable instrument and on development of limited routines (Microsoft; C) for a new digital instrument. Interface routines were written to calibrate the new instrument and to allow acquisition, scaling, and storage of tympanometric and acoustic reflex data. Stored data can be analyzed using software developed for the original instrument. The analysis software supports reduction of tympanometric data, determination of acoustic reflex thresholds, and measurement of amplitude and temporal characteristics of single acoustic reflex responses.

Results—Summary data is derived from raw immittance data and displayed in admittance units (Y_a and phase angle, or B_a and G_a). Summary data for a given test are displayed on a single screen and can be saved to disk or printed out.

Publication Resulting from This Research

Digital Instrument for Measurement of Aural Acoustic Immittance: A Preliminary Report. Robinette LN, Thompson DJ, *Journal of Rehabilitation Research and Development* 23(2):34-47, April 1986.

Presentations

Southern Audiological Society, September, 1985. Robinette LN, Thompson DJ. **Association for Research in Otolaryngology**, 1986. Thompson DJ, Robinette LN.

Southern Biomedical Engineering Conference, Gupta S, Robinette LN, Thompson DJ, 1986.

Establishing Design/Operational Features for Portable Blind Reading Aids

Richard D. Steele, Ph.D.; Gregory L. Goodrich, Ph.D.; Dean Hennies, M.S.; Janice McKinley, M.A.

Rehabilitation Research and Development Service, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This project has four goals: 1) to establish, via questionnaires, what are the demonstrable, unmet needs for reading aids among blind persons; 2) to determine, via technology surveys and follow-up contacts, where new components and systems are appearing to help meet those needs; 3) to establish experimentally, using a flexible reading aid testbed assembled at our Center, together with information from the previous steps, the design and operational specifications for the next-generation reading aid; and, 4) to utilize and disseminate the information acquired promptly and usefully, to those who need it either professionally or personally. The two unifying purposes of these coordinated activities are: a) to provide the information needed to ensure that the next-generation reading aid is yet more useful, affordable, and widely accepted than currently avail-

able devices; and, b) to prepare the ground thoroughly for the design, construction, and preliminary evaluation of a next-generation reading aid prototype, which will use specific components, techniques, and knowledge gained in this project.

Progress—In the past year and a half, the investigators have moved ahead purposefully in each of the areas. 1) To reach the first goal of establishing unmet needs, they have employed questionnaires and interviews. A “general user questionnaire” has been completed and administered by telephone to approximately 150 blind and visually impaired individuals in three groups—veterans (of working or retirement age), non-veterans (on the same age groups), and students (primarily around the college ages of 17-22). In addition, an “expert user ques-

tionnaire'' has been written and is being administered to blind individuals with special experience and expertise in the use of technology to compensate for their disabilities. 2) The survey of current technology has led to the identification of several specific components that appear well suited for a next-generation reading aid, and discussions with the developers of those components have led to cooperative arrangements that hold promise for their eventual inclusion. 3) A series of human performance tests using our Center's reading aid simulator has been completed on blind, low-vision, and fully sighted individuals (the latter to provide baseline measurements). The tests allowed researchers to measure accuracy versus speed under several candidate feedback conditions (audio, tactile, and combined) while hand-tracking a camera over lines of text for optical capture. 4) Dissemination of results is underway: several abstracts are already published in conference proceedings (reflecting talks, posters, and demonstrations presented to the public), while lengthier, more detailed articles are being prepared for submission to the journals.

Preliminary Results—Each of the areas of activity has yielded important results. The user questionnaires have provided a detailed look at comparative usage patterns of existing reading aids (Optacons, KRMs), identified perceived needs which are currently going unmet, and helped us better characterize users' likes, dislikes, biases, and future expectations. The technology surveys and follow-up contacts have allowed the investigators to establish valuable cooperative arrangements with those developing promising technologies for our future device. The human performance studies, using our flexibly configurable reading aid simulator, has allowed the investigators to select the best feedback to blind people who are hand-tracking a camera

across lines of text on a page. Dissemination activities have elicited considerable interest among researchers elsewhere who are working on related questions.

Future Plans/Implications—With the completion of the expert user survey administration, with comprehensive data analysis from each activity area, and with the full publication of results, the investigators conclude their activities under the current project. They will incorporate the knowledge gained, the contacts established, and the components acquired into a follow-up Merit Review submission, in which they will propose to construct a portable, computer-based reading aid prototype for initial evaluation. This aid will be designed to support, additionally, the peripherals of an employment-or home-based workstation for blind individuals.

Publications Resulting from This Research

Survey of Potential Users: Design/Operational Features for Blind Reading Aids. McKinley J, Goodrich GL, Steele RD, Hennies D, *Proceedings of the 10th Annual RESNA Conference*, 451-453, San Jose, CA, June 1987.

Experienced Technology User Survey: Design/Operational Features for Blind Reading Aids. Goodrich GL, McKinley J, Steele RD, Hennies D, Duluk J, *Proceedings of the 10th Annual RESNA Conference*, 443-445, San Jose, CA, June 1987.

Audio and Tactile Feedback Strategies for Tracking. Lasko-Harvill A, Harvill Y, Steele RD, Verplank W, Hennies D, *Proceedings of the 10th Annual RESNA Conference*, 459-461, San Jose, CA, June 1987.

Development of a Portable Text Communication Environment for the Visually Impaired Community. Hennies D, Steele RD, Goodrich GL, and McKinley J, *Proceedings of the 10th Annual RESNA Conference*, 431-433, San Jose, CA June 1987.

A Multibus-Compatible Interface to Selected Reading Displays for the Blind. Steele RD, Miranda RF, *IEEE Transactions on Biomedical Engineering*, 33(9): 896-898, 1986.

Software Modules for a Hand-Scanned Reading Aid for the Blind. Steele RD, Hennies D, Duluk J, Vogel E, McMillan K, *Proceedings of the 9th Annual RESNA Conference*, 43-45, Minneapolis, MN, June 1986.

A Portable Navigational Aid for Blind Persons

Roland Priemer, Ph.D., and John Trimble, Ph.D.

Department of Electrical Engineering and Computer Science, University of Illinois at Chicago, Chicago, IL

Sponsor: *Rehabilitation Research and Development Center Core Funds*

Purpose—Blind persons travel by memorizing routes. In unfamiliar environments they frequently depend on other persons for assistance. This situation not

only increases their dependence on others, but also limits the extent to which they can travel, since it is difficult to memorize many routes. Although some

blind persons are satisfied with this degree of independence, many would like the ability to independently travel unfamiliar environments.

Devices that have been designed to help blind persons travel unfamiliar routes are not widely used. Assistive devices like "talking signs," audio cassettes, or the Sonic Orientation and Navigation Aid have limited scope. Tactual maps are cumbersome and not generally available for many places.

Progress—We have developed a device that will allow blind persons to independently travel unfamiliar routes. The device senses the direction and speed that the person travels each segment of the route. These data are processed by a microcomputer and stored in digital memory. When a person wishes to travel a route, they must first teach it to the device. This is done by simply walking the route. Thereafter, whenever they wish to retrace the route,

they simply command the device to replay the instructions for traveling. The device conveys instructions for traveling the route through tactile stimulators attached to the waist. The device also warns the person that they are deviating from the desired route by signaling them with appropriate tactile stimuli.

Results—A prototype device has been constructed and tested for accuracy and susceptibility to interference from ferromagnetic objects. The results of these bench tests suggest that the device will operate satisfactorily in most environments, even those that have a preponderance of large metallic objects. The prototype device will soon be tested under actual conditions in a dense, urban environment. If this test is successful, we will seek a company to produce pre-manufacturing prototypes for evaluation.

A. Blindness and Low Vision

3. Reading Aids

Computer Vision to Guide the Blind

M. Adjouadi and E.J. Weldon, Jr.

VA Outpatient Clinic, Honolulu, HI; and the Department of Electrical Engineering, The Computer Vision Laboratory, University of Hawaii at Manoa, Honolulu, HI 96822

Sponsor: VA Rehabilitation Research and Development Service; Pacific International Center for High Technology Research (PICHTR)

Purpose—This project deals with the development of a novel computer vision approach for guiding the blind. The principal goal in applying computer vision is to provide the blind with efficient and reliable guidance, improving their mobility needs and bettering their lives in the process. To this end, we exploit in an optimal fashion, and in harmony with the visual features used by humans, the rich information acquired by the camera to yield descriptions of the viewed environment which are most suitable to the blind. In this research direction, we identify and address four important problems: 1) the vision system design; 2) establishing the mapping principles between the two-dimensional (2-D) camera images

(the domain of the computer) and the three-dimensional (3-D) real world (the domain of the blind); 3) development of the appropriate imaging techniques for the interpretation of the 2-D images; and, 4) information integration and output coding in order to establish the proper communication link between the vision system and the blind.

Progress—In the design of the vision system, we are presently assessing the various design aspects, with strong emphasis placed on the current advances in Application Specific Integrated Circuits (ASIC) fabrication and in Very Large Scale Integration (VLSI) technology. The main issues here are that

the vision system should be portable and must operate in real time. Our present vision system is bulky and tethered.

To establish mapping between the 2-D images and the 3-D world, the depth information must be recovered from the 2-D images. To this end, we have devoted a great deal of our research efforts to two distinct methods, motion vision and stereo vision. Good results have been obtained under certain constraints. With the considerable work we have already done on these methods, we have developed significant insight into this problem, and are confident that one of these methods can be adapted to our vision system.

We have developed and implemented successfully the following image interpretation techniques: 1) planning a safe path for the blind to follow. (In this task, we can demonstrate, using our vision system, the whole procedure of providing guidance cues to the blind from image taking to image analysis and interpretation followed by results being displayed on the monitor for visual appreciation); 2) detecting

depressions or drop-offs, for they constitute the type of obstacles most feared by the blind; 3) discriminating upright objects from flat-lying objects, in view of the fact that upright objects may be either obstacles which should be avoided, or landmarks which could be used as necessary cues in the guidance process; 4) identifying shadows, for shadows cast on the path of travel can be mistaken by the vision system for actual objects leading to false alarms; and, 5) identifying, when necessary, those objects which could be important to the blind—such as stairs, crosswalks, curbs, and doorways.

Preliminary Results—Encouraging preliminary results have been obtained for all the imaging techniques mentioned above.

Future Plans/Implications—In the future, we will work on the output interface unit which will consist of an audio unit and a tactile unit. Also, we shall integrate the various imaging techniques to yield an integrated system.

The Human Factors Design of a Large Print Display

Thomas L. Amerson; Lisa W. McNeal; David A. Ross; Gary Kelly, B.S.

Veterans Administration Medical Center, Rehabilitation Research and Development Unit, Decatur, GA 30033

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The study was a design project to develop a device to format large print displays (LPD) for use by persons with limited usable vision. The objective of the project was to determine the display values which enhanced the readability of the LPDs.

Progress/Methodology—The approach taken in this project was to determine the text and display characteristics preferred by the low vision reader and to determine the relationship between these characteristics and the reader's sustained reading performance. The sample subject population consisted of low vision students ($n = 10$) from local high schools.

A Voyager XL Visualtek closed circuit television system (CCTV) was used to obtain the initial assessment of font style and size preference. Several parameters of the LPD were investigated with the CCTV: font style; character size or magnification; and, achromatic polarity of the background/letters. Font styles were varied relative to the stroke width,

the presence of serifs, and the size of descenders. Character size was adjusted to accommodate the individual reader's needs.

The LPDs were generated on two different computer systems: a Hewlett-Packard Model 9000, Series 300 system; and, an Apple IIe with an 80 column card and 64K RAM. The Hewlett-Packard system permitted high resolution font generation, precise manipulation of character and line spacing, and extensive control of letter and background color. The Apple IIe provided an LPD (with some constraint to character size) and, additionally, offered text scrolling capability. The display for the Apple IIe was a standard green monitor.

Each subject participated in two experimental sessions. In the first session, each subject's description of visual impairment and reading behaviors were obtained through a brief biographical inventory. A set of fonts was presented on the CCTV for ratings of readability, desired magnification, and

general preference. Each participant then read passages of the "Timed Readings Test" containing 400 words of factual information. Reading speed and comprehension were assessed for the standardized font used. In the second experimental session, the subject was provided with his/her preferred LPD font styles and sizes on the Apple IIe. The text appeared in a single line in the middle of the monitor screen. The scroll rate of the text could be adjusted by the subject using keyboard input to cursor keys. New passages of the reading comprehension test, displayed in both the standard and the subject's preferred font were presented. Again, the subject's reading speed and comprehension were recorded.

Results—Significant differences were found in the ability to read an optotype (Landolt ring) depending upon the color combination of text and background; however, the ranking of color preference was not related to the ranking of optotype reading performance. Although there were strong preferences in font style, the use of these fonts in the reading of sustained passages was not associated with improved reading performance over the standard font

(Times Roman). The use of computer generated text provided no improvement in reading level over that obtained with the CCTV when the standard font was used.

Future Plans/Implications—One of the major implications of this research for the design of large print displays is that reader preferences for certain textual characteristics (e.g., font style or letter color) may not be sufficient to predict improvements in reading performance. Actual testing of the reading performance (*vis.*, reading speed and comprehension) must be done to confirm the effectiveness of design features in a large print display. Although there are no specific plans for future investigations in this area, the Rehabilitation R&D Unit continues to support related studies in low vision.

Publications Resulting from This Research

Human Factors Considerations in the Design of Large Print Displays for Persons with Visual Impairments. Amerson T, McNeal L, Ross D, *Proceedings of the 10th Annual Conference on Rehabilitation Technology* 7:419-421, San Jose, CA, June 1987.

Adaptation of the Amiga Personal Computer to the Visually-Impaired User

Virginia A. Campbell, M.D.; Dennis G. Smith, Ph.D.; Sabrina A. Calhoun

Southeastern Blind Rehabilitation Center, Veterans Administration Medical Center, Birmingham, AL 35294

Sponsor: *Veterans Administration Core Money*

Purpose—The Commodore Amiga is a relatively new personal computer which offers the potential of addressing some of the common problems faced by visually-impaired users. Features of particular interest are: relatively low cost, high speed, built-in sound and advanced graphics capabilities. To take advantage of these features, appropriate software must be developed which provides large print and/or speech.

Progress—Utilizing Manx C and the documentation

available, a primitive text editor has been developed. Large fonts can be used, but thus far, only one has been designed.

Preliminary Results—Our work has shown that it is technically feasible to adapt the Amiga to the visually-impaired user.

Future Plans/Implications—Future progress will depend on achieving adequate documentation and manufacturer support.

Braille Teaching Aid with Synthetic Speech

John Trimble, Ph.D.; Henry Au-Yeung; Gait Merrit

School of Art and Design, University of Illinois at Chicago, Chicago, IL

Sponsor: VA Rehabilitation Research and Development Center Core Funds

Purpose—Although only 10 percent of blind people regularly use braille, it has many uses for which there is no substitute. Braille is still the only medium by which blind persons can easily take notes and label items. Additionally, accessibility codes mandate braille symbols in many public places. Accordingly, it is a useful language to know. However, few people bother because it is a difficult language to learn, especially for adults.

Traditional methods for teaching braille rely heavily on assistance from braille instructors or sighted persons. This not only reduces the extent to which students can study independently but also affects the instructor's ability to give personal attention to students who need it. Some instructors have attempted to solve this problem by providing audio cassettes to accompany braille material. Although these are helpful, they require the student to expend considerable effort in relating verbal instructions with braille materials.

Progress—We have developed a product that will make it easier to learn braille and give students the freedom to study independently. Our product is a book that combines braille and Talking Tracks™ bar code (Texas Instruments Incorporated). The Talking Tracks produce synthetic speech when read with an inexpensive bar code reader. This design gives students the opportunity to obtain verbal reinforcement whenever they need it, without having to refer

to passages on audio cassettes. Accordingly, they may study without the assistance of a braille instructor or sighted person.

Results—A prototype book has been developed after extensive testing. Twenty books were recently printed using a process that allows embossed materials to be printed with conventional presses. These books have been evaluated by braille instructors at the VA Hines Central Blind Rehabilitation Center, Hadley School for the Blind, Illinois Visually Handicapped Institute, Library of Congress, and the Perkins School for the Blind. The results of these evaluations were generally favorable. Instructors liked the idea but had problems with the design, embossed printing, and bar code reader.

The book's design has been changed to make it easier to locate and scan the bar code. The printer has been contacted regarding changing the formulation of ink to enable printing of braille material that meets existing standards. Additionally, the bar code reader has been modified to make it easier to handle.

Future Plans—We will determine the impact of these changes by printing new books using microcapsule, xerographic paper. We will then re-evaluate the altered books and reader. If the evaluation is favorable, we will reprint the books using the re-formulated ink and test the design on a larger population.

Enhancing the Reading Skills of Low Vision Individuals with Macular Loss

Gale Watson, M.A.Ed.; Steven Whittaker, Ph.D.; William De l'Aune, Ph.D.

Pennsylvania College of Optometry, Philadelphia, PA 19141

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—This overall project is an applied research effort designed to quantify measures of visual and reading skills and to develop computerized training protocols and software that assist low vision instructors in the vision rehabilitation of the target population. The present report represents the work done

during the final year of this 3-year study and a brief summary of results from previous years.

Progress—*Part I. Development of Measures of Visual and Reading Skills.* The Pepper Visual Skills for Reading Test (VSRT) is an instrument designed

to quickly assess the visual skills required for reading. Developed and described in a previous project, it has been refined and revised in the course of the present study. Data has been presented regarding the reliability of the test. Fifty individuals with age-related maculopathy were tested on two forms of the test. The correlation coefficient between the two accuracy scores was 0.90 and between the two reading rate scores was 0.97. In terms of the validity of the test as an assessment of reading ability, assessments with the VSRT were compared with those made on the basis of the Gray Oral Reading Test. Data from 38 subjects with central field losses resulted in a Pearson-product moment correlation of 0.82. The validity data and a discussion of appropriate usage of the instrument is presented in a paper in press (Watson et al., 1987).

Part II. Expert System for Training Eccentric Viewing and Reading. The results of a national survey of 80 clinics providing eccentric viewing and reading training were incorporated into the framework of a computerized system to assist low vision professionals in this area. The resulting three-disk package includes the following modules: Training Flow, Pepper VSRT Scoring Module, Text Difficulty Assessment Module, Text Formatting, Psychological Testing, Training Exercises, Referral Database,

Lighting Advisor, and General Report Generator. The information gathered through the use of the modules is recorded on an accompanying data disk for future research. The documentation and final beta-testing of the system is currently under way.

Future Plans/Implications—The most interesting and potentially powerful aspect of the computerized system has been the psychological testing module. A proposal to extend this module and develop normative data for the client population and attempt to use this data to generate models which might prove helpful in developing optimum training strategies has been submitted to the National Institute on Disability and Rehabilitation Research.

Publications Resulting from This Research

The Pepper Visual Skills for Reading Test. Watson G, Whittaker S, Steciw M, Pennsylvania College of Optometry, Philadelphia, 1986.

The Development and Evaluation of a Reading Test for Low Vision Individuals with Macular Loss. Baldasare J, Watson G, Whittaker S, Miller-Shaffer H, *Journal of Visual Impairment and Blindness*, June 1986.

Observations from the Psychology of Reading Relevant to Low Vision Research. Baldasare J and Watson G, in *Low Vision Principles and Applications*, G. Woo (Ed.), Springer Verlag, 1986.

Software Development: Blissbook

S. McNaughton, B.A., M.Ed.; P. Parnes, B.Sc., D.S.P.A.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: Ontario Ministry of Education, Exemplary Software Project

Purpose—Blissbook is designed to provide an introduction to the reading of words for the student who communicates with Blissymbolics. The primary objective of the program is to facilitate the learning of traditional orthography through acquiring skills in the processes of writing, editing, and reading within the medium of Blissymbolics. The secondary objective is that the student direct the pace and content of this learning.

Progress—Blissbook requires a 512K ICON computer. Although it is a scanning program for students who use a single switch, direct keyboard access is also possible. Blissbook consists of four sections: Write, Read, Activities, and Utilities. The student

first composes a story in Blissymbols. At a pace set by the student, the Blissymbols may be converted to traditional orthography. Blissbook provides a variety of functions (e.g., insert, delete, gloss on/off, scan time) which enable the student to edit his/her stories and to control the screen environment. A special function, *Transform*, allows the student to convert the Blissymbol gloss to an approximation of standard English syntax. Through the *Utilities* section, the instructor, along with the student, may set up various program parameters according to the student's needs. Communication will be achieved through the video screen, synthetic speech and hard copy printout.

B. Deafness and Hearing Impairment

Electroacoustical and Clinical Protocols for Evaluating Assistive Listening Devices

Lucille B. Beck, Ph.D., and Harriet Kaplan, Ph.D.

Veterans Administration Medical Center, Audiology and Speech Pathology Service, Washington, DC 20422

Sponsor: VA Rehabilitation Research and Development Service (Pilot Project #C944-PA)

Purpose—People who suffer from hearing loss do not receive adequate help from hearing aids in situations where there is background noise or where the speaker is some distance away. Hearing aids amplify all wanted and unwanted signals in their range, both the interfering background noise and the speech. Examples of distance listening where hearing aids are of limited benefit include attending church services, going to a movie or play, and watching television at home.

Assistive listening devices are very useful in both noisy and distance listening situations because they use special microphones which are placed close to the speaker and transmit the signal directly to the hearing impaired listener. In this way the important message is transmitted without picking up the interfering background noise or losing the intensity of the signal because the speaker is a great distance away.

The purpose of this pilot project is to develop methods for the evaluation of these assistive listening devices to determine which of the many devices meets the needs of the particular hearing impaired individual. The audiologist must have reliable infor-

mation about how the device amplifies sound and how to evaluate the device on the patient. An electroacoustic protocol will be developed to determine how the device amplifies sound. Technical specifications will be developed that describe how much amplification is provided in the various pitch ranges and how effective the microphone and amplifier are in reproducing the signal effectively.

A clinical protocol will be developed that will measure the effectiveness of the assistive listening device while it is worn by the hearing impaired person. The measures will include determination that the required amount of amplification is present by measuring the amount of sound in the ear canal with a miniature microphone. The ability to understand speech while wearing the device will be measured by having the person listen to words in a background of interfering noise and repeat the words heard. Patients wearing the device will also report how much they understand by judging whether or not they feel the words are intelligible. They will also judge whether or not the quality of the device is good by reporting on how pleasant the speech sounds.

Development of a Digital Hearing Aid and Computer-Based Fitting Procedure: Phase II

A.M. Engebretson, D.Sc.; R.E. Morley, Jr., D.Sc.; G.R. Popelka, Ph.D.

Central Institute for the Deaf, St. Louis, MO 63110; Washington University, St. Louis, MO 63130; Veterans Administration Medical Center, Temple, TX 76501

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this research is to develop a new hearing assessment and hearing aid fitting procedure in which a new digital hearing aid concept plays a key role.

Progress—A digital hearing aid is under development that can provide the flexibility and control of audi-

tory signal processing required to match the patient's hearing deficiency along with an automated hearing test facility that measures the patient's hearing and that programs the hearing aid to provide an optimum setting for the patient. The incorporation of the final hearing instrument as an integral part of the hearing aid evaluation is a key feature of the approach and

represents a radical departure from traditional hearing aid evaluations. The hearing instrument used during testing is the same unit that will be worn home by the patient and includes the acoustic plumbing and earmold configuration specific to that patient. An obvious advantage is that instrument characteristics that vary from patient to patient are taken into account during the hearing evaluation. Fitting errors that arise due to assumptions about calibration with standard cavities are minimized. In addition, the hearing evaluation and fitting procedure can be simplified and shortened with concomitant benefits to the patient.

Work this year has been concentrated in three research areas. They are: 1) development of an adaptive feedback equalization algorithm; 2) comparison of digital hearing aid and conventional hearing aid performance through psychoacoustic studies and clinical field trials; and 3) development of full-custom Very Large Scale Integrated (VLSI) circuitry which operates at low power consumption levels. Progress in each area is described below.

Preliminary Results—Major parts of the feedback equalization study have been completed. Experimental ear modules have been fabricated and used to measure the characteristics of typical feedback conditions using a KEMAR manikin. A TMS320-based system has been programmed to implement the Widrow adaptive cancellation algorithm which has been implemented to constantly measure the feedback characteristics and to equalize the overall system. This program runs in real time and has been evaluated under various conditions of ear-mold seal, signal, and noise. The algorithm is simple and suitable for implementation in VLSI form.

Our preliminary results in the laboratory with the above system have been very promising. The algorithm is stable over a wide range of adaptation rates. The algorithm appears to equalize the acoustic feedback so that significantly greater system gains can be achieved with equalization than without. Finally, the quality of the sound through the equalized system is good.

Future Plans/Implications—In anticipation of field trials with the wearable digital hearing aid, several patients from the clinic have been identified as potential research subjects and were asked to re-

spond to questionnaires and to keep a log of specific information (environment condition, difficulty in understanding speech, changes in volume control, reasons for changes in volume control, etc.) while wearing a conventional hearing aid. Information from the logs indicated that this group of patients readjusted their aids on the order of 2-10 times per day under a variety of conditions. The predominant reason given for changing the volume control was to increase understanding of speech. We have also started a series of experiments with hearing-impaired subjects that are designed to provide additional information regarding: 1) differences between the digital hearing aid and conventional aids; and, 2) appropriate overall gain functions. In these experiments, speech intelligibility is measured as a function of signal-to-noise-ratio, overall noise level, and hearing aid parameters.

During the current year several milestones have been reached with regard to VLSI development. At the beginning of the year we received our first full-custom integrated circuit from the fabricator. The chip performs a multiply-accumulate operation on logarithmically-encoded data with a log base of $D=0.908$. This log multiply-accumulate (LMA) cell is the elementary function block required to carry out the linear filtering operations of the digital hearing aid. The LMA cell performs the equivalent of one tap in a Finite Impulse Response (FIR) filter and the four-channel, instantaneous-compression, digital hearing aid requires 256 such FIR taps. Eight chips were received and were tested to verify functionality and power dissipation. All eight circuits passed the functional tests and the measured power consumption was as predicted.

The basic LMA cell design was modified to execute eight FIR filter taps by incorporating multiplexing for the filter coefficients and sampled data. This multiplexed log multiply-accumulate cell (MLMAC) was submitted for fabrication and chips are expected to be received and tested before this year ends.

Our goal of achieving 256 FIR taps on a single chip is being pursued further by combining eight of the MLMAC's into a Systolic Array of Logarithmic Multiply-Accumulate cells (SALMA-8) which will be able to perform all taps needed for one of the four channels in the aid. This design has just recently been submitted for fabrication and chips are expected in late December. Future plans call for

combining four of the SALMA-8 arrays into a single chip to complete the evolution of the Digital Signal

Processing chip component of the digital hearing aid.

Perception of Reverberation by the Hearing Impaired

Stanley A. Gelfand, et al.

Veterans Administration Medical Center, Audiology and Speech Pathology Service, East Orange, NJ 07019

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The overall objectives of this research are to determine which aspects of the microstructure of reverberation are important for normal-hearing listeners and which are important for the hearing-impaired and to use this information for the development of signal-processing techniques for enhancing the intelligibility of speech in reverberant conditions for hearing aid users. For these studies, reverberation will be specified in terms of its important microstructure (e.g., density of reflections, spectrum ripple, early versus late reflections). Of particular interest are the effects of between critical-band and within critical-band spectrum ripple on the perception of complex sounds and, in particular, on the intelligibility of speech.

Progress—At the present time, the program is in its initial stage, which is devoted to the generation of test stimuli. Recordings of short bursts of white noise and recordings of speech will be made in two sets of test rooms. One set will consist of real rooms, with reverberation times that range from 80 ms to at least 500 ms. The second set will consist of rooms whose reverberation characteristics will be simulated on a computer. By use of computer simulation it will be possible to manipulate the received reflections so as to examine the effects of early (<10 ms), late (>60 ms), and midrange arrival times of reflections of the directly received sounds.

Direct Measurement of Loudness Recruitment in Hearing-Impaired Veterans

Rhona P. Hellman, M.S.

Veterans Administration Outpatient Clinic, Boston, MA 02108

Sponsor: VA Rehabilitation Research and Development Service

Purpose—To determine the feasibility of using direct magnitude-scaling procedures for the measurement of loudness in a clinical setting, a systematic study of the relation among power-function exponents for individuals with normal- and impaired-hearing was undertaken. Two assumptions underlie this methodological approach. First, individual sensation-magnitude functions are described by a power function in the form $\psi = K\phi^\theta$, where θ is the exponent of the power function. Second, the matching behavior of individuals exhibits the basic mathematical property of transitivity. Thus, from the equal-sensation functions obtained for any two pairs of sensory continua with one continuum in common, the function for the third pair can be predicted.

Progress—A battery of psychophysical procedures

was designed to measure, assess, and predict the loudness exponent for individuals. Three different psychophysical procedures were studied: absolute magnitude estimation (AME), absolute magnitude production (AMP), and cross-modality matching (CMM). The measurements involved two sensory continua, perceived length and loudness. They generated four sensation-magnitude functions for each participant. In addition, since the last progress report, a more precise procedure for data analysis was developed. This revised procedure was used to reevaluate the data obtained in normal hearing; it was applied to the results obtained in impaired hearing. To date, 51 people with normal hearing and 50 people with sensorineural impairment have been tested.

Preliminary Results—Normal Hearing ($N=51$): From these procedures, individual and group measured and predicted loudness exponents were obtained. The results show that both the group means and the individual distributions of loudness exponents measured directly by AME and AMP of loudness closely agree with the predicted values derived from CMM. The differences between the predicted and measured exponents range from -0.43 to $+0.37$ with a mean (and median) difference of 0.0 . More than half of the differences range from -0.07 to $+0.09$, giving measured deviations that extend from 12.5 to 16 percent. Of primary importance, the results demonstrate that transitivity can be achieved for individuals, meaning that CMM can be used successfully to determine the exponent for loudness.

Impaired Hearing ($N=50$): The results for 32 people were completely analyzed; those for 18 people are currently undergoing analysis. Both the individual and group results show that loudness functions derived from CMM are steeper for the 32 people with bilateral noise-induced cochlear losses than for the 51 people with normal hearing. Over the stimulus range where the impaired loudness functions exhibit loudness recruitment, most of the individual exponents lie between 1.2 and 2.2 with a mean value of 1.72 . This value is about three times larger than the mean of 0.56 obtained for the normal-hearing group; only one person with normal hearing lies within the hearing-impaired range. The results also show that, on the average, the slope of the loudness function depends on the severity of the hearing loss. The more severe the loss, the steeper is the loudness function. For threshold shifts from 40 to 70 dB, the slope increases by a ratio of $1.7:1$, in agreement with the increase in slope measured for the loudness of tones masked by broadband

noise.

Future Plans/Implications—The findings imply that CMM offers much promise as a clinical tool for the measurement of loudness in impaired hearing. Future experiments are planned with a larger and more diverse population of people with sensorineural impairment. The proposed research program is expected to improve the hearing aid evaluation and selection process.

Publications Resulting from This Research

- Perceived Magnitude of Noise-Tone Complexes: Relation to Loudness and Masking.** Hellman R, *Proceedings of Inter-Noise '85*, Munich, Germany 2:929-932, 1985.
- Group Estimation of Loudness in Sound Fields.** Canevet G, Hellman R, Scharf B, *Acustica* 60:277-282, 1986.
- Is High-Frequency Hearing Necessary for Normal Loudness Growth at Low Frequencies?** Hellman R, Meiselman C, (invited paper) *Proceedings of the 12th International Congress on Acoustics*, Toronto, Canada 1:B11-5, 1986.
- Using Psychoacoustics to Understand Annoyance of Discrete Tones in Noise Emissions.** Hellman R, *Proceedings of Inter-Noise '86*, Cambridge, MA 2:873-878, 1986.
- Limitations of First-Order Approximations for Calculations Using Intensity Jnd's.** Hellman R, Hellman W, *Journal of the Acoustical Society of America*, 80:1341-1345, 1986.
- On the Relation Between the Growth of Loudness and the Discrimination of Intensity for Pure Tones.** Hellman R, Scharf B, Teghtsoonian M, *Journal of the Acoustical Society of America* (in press).
- Measured and Calculated Loudness of Complex Sounds.** Hellman R, Zwicker E, (invited paper) *Proceedings of Inter-Noise '87*, Beijing, China (in press).
- Loudness Relations Among Broadband Noises with Different Spectral Shapes.** Hellman W, Hellman R, *Proceedings of Inter-Noise '87*, Beijing, China (in press).
- Can a Decrease in dB(A) Produce an Increase in Loudness?** Hellman R, and Zwicker E, *Journal of the Acoustical Society of America*. Accepted for publication.
- On the Growth of Loudness in Noise-Induced Hearing Loss.** Hellman R, *The 5th International Congress on Noise as a Public Health Problem*, Stockholm, Sweden (in preparation).

Direct Measurement of Loudness Recruitment in Hearing-Impaired Veterans (Project Extension)

Rhona Hellman, M.S.

Veterans Administration Medical Center, Boston, MA 02130

Sponsor: VA Rehabilitation Research and Development Service (Project #XC296-2RA)

Purpose—Despite recent advances made in loudness-measurement procedures, these advances have not been translated into a viable clinical procedure. The work proposed will continue and extend the

work accomplished. A continuation of the current work will enable the further development, testing, and standardization of a direct psychophysical scaling procedure designed to measure loudness in

sensorineural impairment. This procedure is ideally suitable for the measurement of loudness in bilateral impairment, regardless of the underlying etiology of the hearing loss or the person's age. The primary goal is to systematically study the relations among sensation-magnitude functions in impaired hearing. To achieve this goal, the following experimental studies of a large and diverse population of people with sensorineural impairments will be carried out: 1) determination of the relations among four sensation-magnitude functions for each person; 2) determination of a possible relation between the shape of the audiogram and the pattern of loudness growth; and, 3) measurement of loudness, annoyance, and noisiness functions measured for the same people is planned so that the usable dynamic range for loudness can be defined and specified. The possibility that annoyance increases with signal level at a faster rate than loudness, exceeding loudness at high levels will also be explored.

The subjects for the proposed studies, all with a diagnosis of sensorineural impairment, will be volunteers recruited mainly from the adult veteran population. They will be obtained from both the Audiology Unit and the Normative Aging Study located at the Veterans Administration Outpatient Clinic. Two hundred and thirty-two people with sensorineural impairment of different presumed causes (e.g., aging and noise-induced) will be tested. Three difference psychophysical procedures will be studied: magnitude estimation, magnitude production, and cross-modality matching. The measurements

will involve two sensory continua, perceived length and loudness. In addition, a limited number of loudness balances, either ABLB or MLB, will be performed.

The information obtained from the proposed continuation and extension of the project is essential for the differential diagnosis of auditory pathology, for determination of the degree of recruitment and the consequent dynamic range for loudness, for assessment of the tolerable loudness-growth range, and for hearing aid evaluations. Especially important is the potential to distinguish better between cochlear and retrocochlear impairments. In the process, some light may be shed on the complex disorder associated with aging known as presbycusis. Furthermore, the results may be germane to the known, but little understood phenomenon of over-recruitment, as well as to loudness-comfort levels of pure tones. Knowledge of the loudness-growth range will be of immense value to the audiologist who must individually adjust hearing aid mechanisms such as the acoustic-gain and amplitude-compression controls for a maximum usage and minimum discomfort. This procedure is usually long and tedious. Thus, access to more detailed and precise loudness-growth information will not only facilitate diagnosis, but it will also improve the overall quality of care of the hearing-impaired veteran.

The long-term objective of the project is to determine how best to implement the newly developed procedure into the routine clinical evaluation process.

Rabbit ERG Responses to White-Noise Modulated Stimuli

Arthur Koblasz, Ph.D.

Georgia Institute of Technology, Atlanta, GA 30332

Sponsor: VA Rehabilitation Research and Development Service

Purpose—During the past 2 years, we have developed the necessary equipment and computer programs to characterize the Electroretinogram (ERG) response to simultaneous white-noise modulated stimuli of visible light and electric current. We have tested the programs on simulated data and verified that there are no errors in the hardware or software. We have also constructed special contact lenses for our proposed rabbit protocol, with platinum electrodes fabricated and installed into the contact lenses

by the Huntington Institute in Pasadena, CA.

Progress/Methodology—The vertebrate retina is comprised of organized layers of different cell types that presumably interact in a deterministic nonlinear manner. An electrical potential applied across the retina polarizes all of the cells oriented parallel to the potential gradient, i.e., predominantly receptors, bipolars, and Mueller cells. However, the investigators have demonstrated that the induced polari-

zation is greater for the cells which penetrate the R-membrane, i.e., receptors and Muellers. It is thus possible to produce a visual response that is initiated at the same time in the receptor and Mueller layers. The resulting perception of an electrical stimulus is a uniform field of white light, consistent with a rod-initiated response.

When a light stimulus is superimposed onto the electrical stimulus, the two stimuli will interfere with each other. For example, if the light stimulus occurs first, then all of the retinal cells will be refractory for different periods of time following the light stimulus and will not respond to the electrical stimulus for a brief period of time. This interference effect would be no different than two sequential light stimuli, if it were not for the fact that all of the vertically oriented cells are affected by the electrical stimulus at the same time. Hence, we have hypothesized that it is possible for the electrical stimulus to occur later and still reach the Mueller cells first. The resulting ERG would contain an A-wave produced by the light stimulus.

Preliminary Results—If the two stimuli are white-

noise (i.e., quasi-random) modulated, then the first-order kernels indicate the expected impulse (i.e., flash) response to each separate stimulus. In all eight experiments thus far conducted, the first-order kernels for the light stimulus have both the A- and B-waves suppressed. This evidence may indicate that the electrical stimulus triggers both the receptors and Muellers before the light stimulus has a chance to elicit a photochemical response. The first-order kernels for the electrical stimulus all seem to be unaffected by the light stimulus, consistent with the above hypothesis.

Future Plans/Implications—The second-order cross kernels indicate how (mathematically) the two independent stimuli interfere with each other. The main diagnostic value of this information will be to reveal how the Mueller cells interact with other retinal cells and to quantify changes in these interactions associated with different retinal diseases. We are hoping to determine the normal interference characteristics in this study, and then propose a continuation study of the effects of selected pathologies on first- and second-order kernels.

Development of Materials for Computer-Assisted Instruction in Lipreading

Lennart L. Kopra, Ph.D.; Martha A. Kopra, M.Ed.; Judy E. Abrahamson, M.A.; Robert J. Dunlop, Ph.D.
Department of Speech Communication, University of Texas at Austin, Austin, TX 78712 and Olin E. Teague
Veterans Center, Temple, TX 76501

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The goal of this program is an examination of the effects of supplementary drill and practice with an auditory-visual laser videodisc interactive system (ALVIS) on the development of lipreading skill. A computer system has been designed and software has been written for ALVIS and is being used for drill and practice in computer-assisted interactive video (CAIV) instruction in lipreading. The system includes: a laser videodisc player, microcomputer, keyboard, video monitor, two micro floppy disk drives, dot-matrix printer, external amplifier and attenuator, programmable attenuator with associated accessories, and earphones.

Progress—Twelve lists of 25 sentences each have been standardized and arranged in order of difficulty as lipreading stimuli. These five- to eight-word

sentences were recorded on 1-inch videotape and then pressed on videodisc. Presentation of the 300 sentences is under software control by ALVIS in each of two conditions. In the first condition, no sound is given; the *word clues* (ALVIS/word) are presented on the video monitor for a maximum of five trials. In the second condition, *auditory clues* (ALVIS/hear) accompany the visual stimulus (0dB, 5dB, 10dB, and 15dB re the subject's binaural speech noise detection threshold) for a maximum of five trials. Student response data are recorded on microfloppy disk.

ALVIS has been used experimentally with post-lingually hearing-impaired adults in a program of aural rehabilitation that includes lipreading instruction. Six subjects received group lipreading lessons twice each week for 6 weeks. On days following

group instruction, each of two subjects received lipreading drill and practice in one of three conditions: 1) with ALVIS/word; 2) with ALVIS/hear; and, 3) face-to-face with the lipreading instructor. Thirty-six subjects have participated in group lipreading instruction: 12 have received drill and practice with ALVIS word clues, 12 with auditory clues, and 12 have received face-to-face practice with the lipreading instructor.

Data have been analyzed to determine the effects of CAIV instruction on the development of lipreading performance and the effects of group instruction on the degree of self-perceived hearing handicap.

Preliminary Results—The results are summarized as follows: 1) for the 36 subjects in the three groups, pre-test and post-test results of the Utley Lipreading Test and the Denver Quick Test of Lipreading are significantly correlated (r s range from 0.81 to 0.91); 2) significant improvement in lipreading scores (Utley and Denver) occurred during the 6-week period of group lipreading instruction; 3) there were no significant differences between the amount of improvement in lipreading scores across the three groups (ALVIS/word, ALVIS/hear, and face-to-face); 4) pre-test and post-test section scores on the Hearing Performance Inventory (HPI) revealed no significant differences, indicating that the subjects' self-perceived degree of hearing handicap had not changed as a result of the intervention (the implications of

anecdotal information indicating that communication function has improved for almost all of the subjects are being examined); and, 5) the HPI section scores of the subjects' spouses ($n = 20$) tended to indicate that spouses perceived their husbands/wives as having more difficulty hearing in a variety of listening situations than the subjects did.

Future Plans—The 36 subjects who participated in the group lipreading instruction and in lipreading drill and practice sessions are returning for an annual reevaluation of the status of their communication function. The long-term effects of the aural rehabilitation program they received will be summarized as data become available.

Publications and Awards Resulting from This Research

Development of Sentences Graded in Difficulty for Lipreading Practice. Kopra LL, Kopra MA, Abrahamson JE, Dunlop RJ, *Journal of the Academy of Rehabilitative Audiology* 19:71-86, 1986.

Lipreading Drill and Practice Software for an Auditory-Visual Laser Videodisc Interactive System (ALVIS). Kopra LL, Kopra MA, Abrahamson JE, Dunlop RJ, *Journal for Computer Users in Speech and Hearing* 3:58-68, 1987.

A Survey of Microcomputer Applications in Aural Rehabilitation. Sims DG, Kopra LL, Dunlop RJ, Kopra MA, *Journal of the Academy of Rehabilitative Audiology* 18:9-26, 1985.

Second Award for Scientific Merit. *Scientific exhibit: Laser videodisc interactive system for computer-assisted instruction in speechreading*, American Speech-Language-Hearing Association National Convention, Washington, DC, 1985.

Personal Computer System for Acoustic Measurements

Vernon D. Larson, Ph.D.; Christopher J. Ahlstrom, Ph.D.; William A. Cooper, Ph.D.
Veterans Administration Medical Center, Augusta, GA 30910

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this research program is to study variables which influence the measurement or prediction of an individual's performance with a hearing aid. The purpose of this report is to describe progress made to date in developing a system, based on a personal computer, which may be used to evaluate experimental models of the *in-situ* hearing aid.

Progress—The system developed is a general purpose acoustic measurement system, but is specifically configured to make magnitude and phase meas-

urements of the performance of earphones on ears and acoustic couplers. Three routines for estimating the acoustic impedance of transducers have been completed and routines (which are based on a "two-load" method) are nearly completed for estimating acoustic impedance at a defined location in the ear canal.

The software package developed for this purpose consists of a combination of dBASE III Plus (Ash-ton-Tate, Inc.) and Lattice C (Lattice, Inc.). The dBASE portion provides a convenient user-interface while the C portion provides the detailed operations

and control of sampling hardware. Four user options lie at the root of a dBASE menu: reading or making spectral acquisition set-ups, acquiring spectral data, manipulating the data (individual and group) and filing the data. The dBASE programs associated with the menus call C routines to do the specific procedures.

Publications Resulting from This Research

Personal Computer System to Acquire and Display Ear Canal

Spectra: An Exhibit. Larson VD, Ahlstrom CJ, Egolf DP, Cooper WA, Talbott RE, *ASHA*, 19, 1987.

A System for the Acquisition and Analysis of EEG Signals Evoked by Audio Stimuli. Brown BD, Gowdy JN, Larson VD, *Proceedings of the IEEE Southeast Conf 85*, 272-276, 1985.

The Acquisition of Tympanometric Spectra on the IBM PC-XT. Larson VD, Ahlstrom CJ, Schwartz DM, DeChicchis AD, Raevsky PF, Harrell DA, *ASHF Computer Conference*, 46, 1986.

The Constant-Volume-Velocity Nature of Hearing Aids: Conclusions Based on Computer Simulations. Egolf DP, Haley BT, Larson VD, *Journal of the Acoustical Society of America*, 79(5):1592-1602, 1986.

Threshold Sound Pressure Levels (SPLs) for the ER-3A Insert Earphone

Vernon D. Larson, Ph.D., and William A. Cooper, Ph.D.

Veterans Administration Medical Center, Augusta, GA 30910 and University of South Carolina, Columbia, SC 29208

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this research program is to study variables which influence the measurement or prediction of an individual's performance with a hearing aid. The purpose of this report is to describe the results of a project designed to compare auditory thresholds produced by a standard earphone and a hearing-aid-like earphone (the ER-3A).

Progress—Auditory thresholds for tonal stimuli (125 to 8000 Hz) were obtained from 90 normal subjects and 25 subjects with middle ear pathology. Test-retest studies were conducted on thirty normal subjects. All thresholds were expressed in terms of the sound pressure level (SPL) developed in couplers meeting the requirements for the NBS-9A and an HA-1 coupler for the TDH-50 and ER-3A earphones respectively.

Results—The results demonstrated that the ER-3A

earphone, when coupled to the ear canal with a rubber eartip, produces estimates of auditory threshold in normal observers as reliable as those produced with a standard earphone, but it provides a different estimate of minimum audible pressure (MAP) at the eardrum for lower frequencies. The differences in MAP are most likely attributable to effects related to changes in the dimensions of the residual ear canal. For the subjects with middle ear pathology, preliminary analysis of the air-conduction thresholds suggested that factors other than normal inter-test variability contributed to the differences observed with the two earphones.

Publications Resulting from This Research

Insert Earphones and Conductive Hearing Loss. Larson VD, Cooper WA, Talbott RE, Schwartz DM, Ahlstrom CJ, DeChicchis AD, *ASHA*, 28, 1986.

A Comparison of HA-1 2-ml Couplers. Larson VD, Ahlstrom CJ, Cooper WA, Rainbolt HB, *ASHA*, 29, 1987.

Effects of Manipulation of the Impedance of the Ear of Normal Subjects on Selected Indices of Auditory Function

Vernon D. Larson, Ph.D., and William A. Cooper, Ph.D.

Veterans Administration Medical Center, Augusta, GA 30910 and University of South Carolina, Columbia, SC 29208

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The studies reported herein are part of an ongoing program devoted to delineating the inter-

action of the acoustic impedance of the source (earphone, hearing aid, etc.) and the impedance of

the load, as represented by the ear canal and middle ear, on the spectra of acoustic signals in the ear canal and the subsequent transfer of acoustic information through the middle ear.

Progress—Several procedures were used to alter driving point impedance: changes in external ear canal air pressure; elicitation of the middle ear muscle reflex; inversion of the subject; and delivery of the signal through hearing aid earmolds of varying insertion depth in order to change the ear canal volume. Indices of performance included ear canal spectral measures, pure tone thresholds, word recognition ability, and median plane localization ability.

Results—While the effects of trans-tympanic air pressure differences and of the acoustic reflex on auditory thresholds are similar, the effects on word recognition are markedly dissimilar. In a group of normal listeners ($N=30$), as the ear canal air pressure was changed from ambient to -200 or $+400$ daPa, word recognition ability was systematically and dramatically reduced with performance being directly related to presentation level and the magnitude of pressure change.

Using a reflex activating stimulus, which was unlikely to interfere with word recognition by producing masking, by either central or contralateral-direct mechanisms, and in an adaptive procedure used to determine presentation levels at which 30 percent and 70 percent correct scores were obtained, a group of normal listeners required a presentation level 4 to 8 dB less intense when the reflex was activated.

Reasoning that, because of the similar effect on auditory threshold, spectral shaping was not a sufficient explanation for the decrease in word recognition observed, it was speculated that stiffening the ossicular chain by air pressure changes may have produced other forms of distortion. Accordingly, an experiment was designed to determine the possible

effect of trans-tympanic pressure differences on median plane localization. The results indicated that the ear with the air pressure changes lags the other by 47.6 and 59.5 degrees at $+200$ and $+400$ daPa respectively. Therefore, the role of phase shifts through the middle ear is currently under study.

Studies of the relationship of ear canal volume and auditory threshold and ear canal sound pressure levels (SPLs) have been completed. The results obtained show that the SPLs in the ear canal associated with the smaller volume are greater than that associated with the larger volume. Conversely, the thresholds obtained with smaller volumes required less (coupler) SPL than those obtained when the volume was larger.

The changes in both the canal SPLs and the threshold SPLs were greater in the low frequencies and negligible above 1000 Hz. The changes are greater than would be predicted by the simple ratio of the volume differences or by the ratio of driving point impedances. These data are currently being considered in the context of a model of aural acoustic impedance.

Finally, an experiment was completed in which an attempt was made to simulate the effects of increased cochlear impedance by noting the changes in ear canal SPL observed when subjects were studied in both an upright and in a body-inverted position. When a companion effect of body inversion and increased middle-ear pressure was controlled, there was a slight increase in sound pressure for frequencies below the middle ear's resonance. For frequencies above resonance, the changes were sometimes large and varied extensively across subjects. Clearly, the change in terminating impedance influenced the ear canal sound pressures.

Publications Resulting from This Research

Relationships Among Admittance, Ear Canal Spectra and Body Position. Cooper WA, Larson VD and Ahlstrom CJ, *Abstracts of the XVIIIth International Congress of Audiology*, Prague, Czechoslovakia, 46, 1986.

Voice and Speech Findings in Prospective Cochlear Implant Candidates

Steven B. Leder; Jaclyn B. Spitzer; J. Cameron Kirchner; Frederick Richardson; Paul Milner;
Carole Flevaris-Phillips

Veterans Administration Medical Center, West Haven, CT 06516

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This research project has studied the effects of adventitious profound hearing impairment on speech and voice production. Emphasis was placed on the acoustical and perceptual investigation of fundamental frequency, intensity, and duration. Previous studies showed that adventitious profound hearing impairment resulted in both acoustical and perceptual changes in speech and voice quality. Specifically, fundamental frequency became significantly higher and intensity became significantly greater in the speech of adventitiously profoundly deaf subjects. The purpose of the present study is to examine rate and duration in the speech of the adventitious profoundly hearing impaired. The factors of length of time since onset of hearing impairment and history of hearing aid use were also considered.

Progress—The sample consisted of 25 adventitiously (post-lingually) profoundly hearing-impaired male experimental subjects and 10 adult male control subjects. Unaided three-frequency (500, 1000, and 2000 Hz) pure-tone averages in the better ear ranged from 90–125 + dB Hearing Level (ANSI, 1969) for the experimental subjects. Hearing acuity was within normal limits bilaterally for the control subjects.

The stimuli consisted of the first paragraph of the Rainbow Passage (Fairbanks, 1960). All stimuli were read once and recorded at the subject's normal rate in a single-walled audiometric room. The onset and offset of each recorded sentence was identified on a storage screen, and absolute durations (sec) obtained (Kay Visi-Pitch, 6087DS). Total paragraph duration was determined by adding the times for the six individual sentences, thereby excluding pauses between sentences. Syllables per second were determined by dividing the number of syllables in each sentence and the paragraph by the time required to produce the stimuli.

Preliminary Results—The adventitiously profoundly hearing-impaired group exhibited significantly longer

($p < 0.01$) speaking duration values and significantly fewer ($p < 0.01$) syllables per second than the normal-hearing group for both sentences and the paragraph. The time needed for the hearing-impaired group to read the paragraph was 35 percent longer than the time required by the normal-hearing group. No significant differences were observed for subject groups with profound hearing loss of less than 10 years versus greater than 10 years, or for subject groups currently wearing a hearing aid versus not wearing a hearing aid.

Adventitious profound hearing loss had a negative effect on speaking rate. The observed decrease in speaking rate and corresponding increase in speaking duration were similar to results obtained in prelingually deaf subjects.

Future Plans/Implications—It has been shown that teaching appropriate duration patterns of speech improved speech rhythm, which enhanced speech intelligibility. Similarly, appropriate rate of speech should be stressed during aural rehabilitation with adventitiously profoundly hearing-impaired speakers who exhibit speaking rate abnormalities. Therapy directed at decreasing phonation time, thereby increasing syllable rate, should focus on utilizing the intact visual, tactile, and kinesthetic sensory feedback channels, due to the paucity of available auditory input.

Speech tracking, although originally designed to increase speechreading efficiency, is a technique that can be adapted to increase speaking rate. In this technique, the incoming message determines rate of speech production, allowing for a range of increasing speaking rates. Self-monitoring of speech output is required by the subject in order to match the rate, sound, feel, and look of the incoming message. The present application of aural rehabilitation has the dual purpose of improving the hearing-impaired speaker's speech rhythm and making speech more natural sounding.

Basic Mechanisms and Rehabilitative Strategies for Presbycusis

Brenda M. Ryals, Ph.D.

Veterans Administration Medical Center, Richmond, VA 23249

Sponsor: VA Rehabilitation Research and Development Service (Project #XC251-2RA)

Purpose—We have shown, through experiments using pure tone acoustic trauma, that the frequency organization of the cochlea changes during early and post-natal development. Further electrophysiological studies have confirmed that the cochlear response to various frequency stimulation is dynamic and mutable in early life. Whether this mutability continues in later life is still unknown. The consequences of such mutability are many. Changes in cochlear frequency organizations as we propose could define one of the basic mechanisms of hearing loss in old age. Once this mechanism has been defined the potential for reversal or prevention exists. Further, a changing frequency organization could result in altered perception of loudness and/or pitch in the elderly thus changing their preference for gain and frequency response characteristics in hearing aids and other amplification devices.

The purpose of the proposed experiments is: 1) to further explore the possibility of a changing frequency organization at the cochlear level with aging; and, 2) to examine the possibility of an altered preference for frequency and/or gain characteristics in amplification devices that might correlate with

this altered frequency organization. Pure tone acoustic over-stimulation has been used to define frequency organization in the mammalian cochlea. We have shown that it can be used with similar specificity for frequency organization during development. In the proposed experiments pure tone acoustic over-stimulation is used to create discrete, localized regions of sensory cell loss. The location of sensory cell loss is used to define frequency organization during aging.

In a recent study using probe microphone measurements comparing real ear insertion gain in young and old experienced hearing aid users we found that less gain was preferred, especially for the lower frequencies, in the older group. The proposed set of experiments are considered likely to provide insight into at least one of the basic mechanics involved in the deterioration of hearing during aging. By concurrently analyzing the rehabilitative process in the elderly these experiments will apply our theoretical concepts at the soonest possible time so that the best auditory rehabilitative process can be provided at the earliest possible time.

Changes in Frequency Organization of the Cochlea During Aging

Brenda M. Ryals, Ph.D., and Edwin W. Rubel, Ph.D.

Audiology and Speech Pathology Service, Veterans Administration Medical Center, Richmond, VA 23249 and Department of Otolaryngology, University of Washington, Seattle, WA 98195

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of the current project is: 1) to determine the normal auditory morphological and electrophysiological profile within one species (*Coturnix Quail*) during its entire predicted lifespan in order to use this as a model for further study of mechanisms in presbycusis; and, 2) to determine if shifts in frequency organization at the cochlea, such as we have seen in early development, are also seen in the later declining years of life. These studies are expected to yield important information regarding the basic mechanisms of presbycusis.

Progress—Using plastic embedded serial sections, we have performed qualitative and quantitative light microscope analysis of the hair cells of the basilar papilla (cochlea) as well as the ganglion cells of the VIII nerve. Quails from age 3 months to 7 years (actuarial lifespan = 2 years) have been examined.

Preliminary Results—Very little difference in total hair cell number has been found over the actuarial lifespan of the quail (3 percent). Qualitatively, the accumulation of inclusion bodies, probably lipofus-

cin, was noted in the supporting cells as well as in the hair cells. Lipofuscin accumulation has also been noted in the hair cells and supporting cells of aged humans. Even at 150 percent of predicted lifespan (6-7 years) very little total hair cell loss was seen (6 percent). Ganglion cell loss, on the other hand, was much greater as a function of aging. A 25 percent reduction in the number of ganglion cells was seen over actuarial lifespan. By 6-7 years of age approximately 61 percent of ganglion cells are lost.

Far-field compound VIII nerve action potentials (AP) have been recorded in quail from 3 months to 3 years of age. The average AP threshold for tonebursts from 250Hz to 6000Hz in young adult quail (3 months) are very similar to those reported for other, non-passerine birds. No change in AP thresholds was seen up to 1 year of age. At 2 years of age some loss of sensitivity was seen across all frequencies and by 3 years of age (100 percent of actuarial lifespan) a 20dB hearing loss was noted for most frequencies. Because of the relatively flat nature of the hearing loss an examination of click evoked AP latency was performed. No difference in Wave I latency was seen between young and old quail. Anatomical analysis showed no evidence of infection or blockage, therefore, the hearing loss was presumed to be of a non-conductive nature. Finally, analysis of absolute and interpeak latencies

of the click evoked AP was performed. A significant prolongation of Wave III was seen in older birds. Since the hearing loss was not conductive, this latency delay was interpreted as a delay in neural conduction time.

Future Plans/Implications—These results are in good agreement with previous quantitative studies in mammals and suggest that a loss of spiral ganglion cells may be a generalized response to aging in both mammals and non-mammals. Further, the delay in neural conduction time seen in the early component waves of the AP correlate well with the decrease in ganglion cell number. This delay in neural conduction time deserves further study in humans in that it may be an early indicator of neural presbycusis.

Publications Resulting from This Research

Ganglion Cell and Hair Cell Loss in Coturnix Quail Associated with Aging. Ryals BM, Westbrook EW, *Assoc. for Research in Otolaryngology Abstract* 151:119, 1987.

Development of the Place Principle. Lippe WR, Ryals BM, Rubel EW, *Advances in Neural and Behavioral Development*, Volume II, R.N. Aslin (Ed.), Ablex Publishing Co., Norwood, NJ, 1986.

Ontogenetic Changes in the Position of Hair Cell Loss after Acoustic Overstimulation in Avian Basilar Papilla. Ryals BM, Rubel EW, *Hearing Research* 19:135-142, 1985.

Differential Susceptibility of Avian Hair Cells to Acoustic Trauma. Ryals BM, Rubel EW, *Hearing Research* 19:73-84, 1985.

An Auditory Prosthesis for Sensorineural Hearing Loss

William Yund, Ph.D.

Veterans Administration Medical Center, Martinez, CA 94553

Sponsor: VA Rehabilitation Research and Development Service (Project #XDC054-3RA)

Purpose—The object of the proposed research is to determine optimal design parameters and fitting procedures for a new multichannel compression hearing aid for patients with sensorineural hearing loss (SNHL). During the past six years, the initial 8-channel version of the new aid has been developed and tested in the laboratory on over 20 SNHL patients. This 8-channel compression hearing aid proved very effective in helping the patients to recognize speech sounds in the presence of noise—a key problem for individuals with SNHL. The new 8-channel aid not only produced better speech recognition performance than an individually best fit

conventional hearing aid in most patients, but in 20 percent of the patients tested, the 8-channel compression hearing aid produced essentially normal speech recognition in noise even when the speech itself was no louder than the noise. The conventional hearing aid did not produce such a high level of performance in any of these patients. This high degree of success of the initial version of the new aid mandates further work on a compression hearing aid of the same general design. Some aspects of the design of the initial aid suggest that the aid can be improved, while aspects of the results suggest that, in many subjects, even the initial 8-channel

multichannel version of the aid may be more effective than our present results indicate.

The complexity of our multichannel compression hearing aid precluded any attempt to determine optimal design parameters or fitting procedures in the initial experiments. Indeed, all research on multichannel compression hearing aids is limited by the complexity of multichannel compression systems. In response to this problem, the proposed research will begin with the already highly successful preliminary model and concentrate primarily on those parameters of the hearing aid that impact most

heavily upon improved performance, production costs and the length and complexity of the procedures required to fit the aid to the patient. On the basis of the previous results, we expect the proposed research to determine the specifications for a multichannel compression hearing aid that will yield near-normal hearing performance in appreciably more than 20 percent of the SNHL population and that will yield better performance than other hearing aids in the remainder of the SNHL population, as well.

Transition Study of Persons with Hearing Impairments

Michael Bullis, Ph.D.; Bruce Bull; John Freeburg; Joe Sendelbaugh

Teaching Research Division, Oregon State System of Higher Education, Monmouth, OR 97361

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—Little is known about the movement of persons with hearing impairments from the school to the community, a process that has come to be called “transition.” The purpose of this 3-year project is to examine the transition from school to the community for students who are hard of hearing, deaf, or have hearing impairments and secondary disabilities (e.g., deaf-blindness).

Progress—There are four major research thrusts of this project. First, to learn about the transition processes of persons with hearing impairments, an intensive study is being conducted of these students who have left school systems/programs in the Northwest. Longitudinal follow-up and follow-along designs are employed. The follow-up design allows for contact with respondents once, 3 years after they have left the educational setting. The follow-along design differs in that initial contact is made at school exit, and annual contact is continued with these students throughout the project. Both designs utilize multiple data sources to provide a large database.

In addition to the data collection efforts undertaken for the targeted groups, we are also gathering data on comparable groups of students without handicaps from the participating sites, as a control. Second, a national survey of transition-planning mechanisms for the target population has been conducted, and a profile of the service structure is being finalized. Third, an investigation will be con-

ducted in the second project year that will include educators, rehabilitationists, parents of students with hearing impairments, and persons with hearing impairments, to identify weaknesses in existing transition systems. Fourth, variables associated with successful transition mechanisms have been identified via a review of the literature and analysis of exemplary transition linkages. Model transition programs will be summarized and described.

Preliminary Results—All first-year data have been collected for the first objective (follow-up and follow-along studies). These data have been coded and are currently being analyzed. With the addition of second and third year data, the number of subjects included in the study will increase. It is anticipated that by the end of the project a total of 400-500 students with hearing impairments, and an equal number of students without handicaps, will be involved.

The second objective, the national survey of transition planning, has been completed. We have obtained matched pairs of vocational rehabilitation and education surveys from 34 states. (An article has been submitted for publication on the results of this survey.)

Future Plans/Implications—Both follow-up and follow-along studies will continue during the next two years of the project. The investigation to identify

weaknesses in existing transition plans was scheduled to begin in the fall of 1987 and be completed in the fall of 1988.

Variables associated with successful transition are continually being gathered via our different data collection efforts. This information will be disseminated through publications and presentations by project staff. Our overall objective continues to be to improve the transition into the community of youth with hearing impairments. Project outcomes, based on the empirical evidence gathered, will serve to suggest new and innovative ways to assist in the transition processes of secondary students with hearing impairments.

Technology for Sensory Devices for Deaf and Severely Hard of Hearing People

Judith E. Harkins, Ph.D., and Carl J. Jensema, Ph.D.
Gallaudet University, Washington, DC 20002

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—Many people with severe or profound hearing losses make extensive use of devices that take advantage of alternate senses, particularly vision and taction. Despite the proven usefulness of devices such as Telecommunication Devices for the Deaf, visual and tactile signalling systems, and captioning devices and systems, relatively little government-supported development of these devices has been undertaken.

This study is part of a 2-year research and demonstration project for NIDRR on: 1) the need for devices in this category; 2) emerging technologies that should be exploited for this purpose; 3) financing mechanisms to assist consumers in acquiring devices in this category; and, 4) how government might best work with businesses to achieve a greater variety of useful devices.

Progress—During the first year of the project, we conducted 15 focus-group discussions with hearing impaired people about their current uses of technology, opinions about the devices they are now using, and hopes for future devices. An annotated bibliography was created on devices in this category.

Technology-assessment papers were prepared on three areas which seem to hold promise for future development of devices: speech recognition technology for captioning speech; image-processing

Publications Resulting from This Research

Research on the Community Transition of Adolescents and Young Adults with Hearing Impairments: An Annotated Bibliography. Bull B, Bullis M, Sendelbaugh J, Teaching Research Division, Oregon State System of Higher Education, Monmouth, OR (in press).

Review of Research on the Community Transition of Adolescents and Adults with Hearing Impairments. Bullis M, Bull B, Sendelbaugh J, Freeburg J, The Catholic University, National Rehabilitation Center, Washington, DC (in press).

Adolescents and Young Adults with Hearing Impairments. Bullis M, Freeburg J, Bull B, Sendelbaugh J, *Issues and Research in Special Education*, Vol. 1 (Invited chapter), R. Gaylord-Ross (Ed.), Teacher's College Press, New York, NY (in press).

technology for telecommunication of sign language and/or lipreading; and signal processing for detection of acoustic signals in noise.

Mail and telephone surveys were conducted with the goal of identifying financing programs that help consumers to acquire sensory-substitution devices. A directory of sources of financing will be one outcome of the project.

Manufacturers and distributors of sensory devices were interviewed to ascertain whether they used the research or technical assistance available from rehabilitation engineering facilities. Their suggestions were sought on ways that government-supported programs might stimulate development in their industry.

Preliminary Results—A 30-page report available from our program describes the results of our discussions with consumers. Some basic findings: hearing impaired consumers find text output very useful in receiving communication from the environment. They expressed a desire for increased captioning of spoken communication—more captioning of television, including local programming, and of movies. For the future, consumers repeatedly mentioned the potential of speech recognition technology for automated captioning of any and all speech. Despite the existence of visible and tactile signalling systems

for alerting and paging the hearing impaired person, many particular environmental sounds go undetected. Troublesome areas included knowing when something is still on (oven fans, cars, running water) and emergency sirens (in traffic, in case of environmental hazard, in case of natural disaster). Preliminary results from interviews with 14 manufacturers and distributors indicate that this industry has not received much advantage from government-supported research on devices. Many were unaware of the existence of rehabilitation engineering centers. A few were aware of the Trace Center. (These

results do not include the National Captioning Institute.)

Future Plans—In the second year of the project, the technology-assessment reports will be completed and compiled into a volume on emerging technologies that hold promise in this class of devices. A volume of sources of financing for sensory devices will be completed and disseminated. A demonstration activity will be conducted on making sirens of emergency vehicles accessible to hearing impaired people.

Project PALS (Places with Assistive Listening Systems)

Selig Starr and Carolyn Rossick

Self Help for Hard of Hearing People, Inc., Bethesda, MD 20814

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—The goals of this project are to maintain a current inventory of all places in the United States that have assistive listening systems (ALS) and to provide lists of sites with ALS in specific locales in response to requests from hard of hearing people and others with a legitimate interest. The sites include cultural, religious, and community activities.

ALS help hard of hearing people to hear better and understand more in large areas that are subject to interference such as background noise, reverberation, and distance between the speaker and listener. Used with microphones or coupled to an existing public address system, ALS deliver sound directly to the listener's ear at a consistent volume, despite any interference (noise). There are five major ALS types in use: infrared, audio induction loop, FM, AM, and hardwired.

Progress—The project has been publicized widely. Organizations and publications that are concerned with hearing impaired people have been informed of the project. The SHHH chapters and groups (over 200) have been encouraged to help locate ALS sites.

A corps of SHHH volunteers are actively involved. The manufacturers of ALS are providing data on past installations and will provide data on new installations.

The inventory of ALS is maintained in a database on a microcomputer. This allows the data to be searched quickly and organized in a variety of useful ways. The project is in the preliminary stages. There are an estimated 15,000 to 20,000 ALS in the United States; as of September 1, 1987, we have information on about 5,500.

Future Plans/Implications—The plan is to bring the ALS inventory up to date and keep it current through additions and revisions. Depending on resources, the project will be expanded to include an inventory of sites (e.g., hotels) with assistive listening devices to accommodate the communication access needs of hearing impaired people. This would include, for example, telephone amplification devices, TDD's telecaptioning TV decoders, and visual alert systems to alert a hearing impaired person of smoke, fire, knock on the door, telephone call, etc.

AKL Spatiotemporal Representation in a Tactile Aid for the Deaf

Grayson D. Abbott

Creare, Inc., Hanover, NH 03755

Sponsor: *National Institutes of Health*

Purpose—The objectives of this contract are the conduct of a series of studies to evaluate the spatiotemporal pattern recognition capabilities of the skin for conveying speech information to deaf, deaf-blind, and severely hearing-impaired persons. Phase I will consist of an evaluation of the effectiveness of the Auditory/Karhunen-Loeve (AKL) represen-

tation, a Principal Components Analysis of English speech, in conveying the speech code to the skin and the development of a "real-time" AKL system. Phase II will include the determination of the optimum configuration of AKL parameters and the development of a breadboard system of the AKL processor.

Speech Perception Studies—Bimodal and Developmental

Lynne E. Bernstein

Johns Hopkins University, Baltimore, MD 21218

Sponsor: *National Institutes of Health*

Purpose—The research is concerned with speech perception in normal adults and children and profoundly deaf children. A research theme will be perceptual learning, both in terms of development and during periods of training. Bimodal speech perception will be a focus of many of the proposed experiments. Combinations of stimulation to two out of the three senses, audition, vision, and somesthesia, will be used to examine basic constraints on bimodal speech perception as well as to evaluate schemes that may have practical significance in the design of aids for the profoundly deaf.

Progress—Project I is a systematic study of candidate transformations between voice FO and single channel vibrotactile stimulation. Results will be incorporated in a long-term evaluation of aided lipreading by hearing, "artificially deafened," young adults. Project II is a series of experiments on coding cues to segmental phonetic distinctions. Audio-visual and tactile-visual stimulus presentation will be used in a standard procedure that allows for comparison across coding schemes. Project III is

concerned with normal development of speech perception between ages 3-4 years and early adolescence. Experiments will be used to study whether there is a developmental hierarchy of phonetic segmental cues. Project IV continues current work on tactile sensitivity thresholds as a function of age and stimulus waveshape. Prelingually, profoundly deaf children will be tested to determine whether vibrotactile perception is affected by auditory experience. Work on Project IV will also include development of training and testing protocols using computer graphics. Protocols will be developed to train and test children on bimodal speech perception schemes. The proposed research is particularly important for individuals whose hearing loss is such that they are unable to derive significant speech information from the auditory channel. Electrical stimulation of the cochlea (implant) is gaining increasing attention as an aid for the deaf. At this time, as young children are having this expensive and traumatic implant operation, it is important that progress be made in devising wearable vibrotactile aids as a reasonable alternative.

Tactile Communication of Speech

Nathaniel I. Durlach

Massachusetts Institute of Technology, Cambridge, MA 02139

Sponsor: National Institutes of Health

Purpose—The ultimate goal of our research program is to develop tactile aids for the deaf and deaf-blind that can serve as substitutes for hearing in speech communication. To the extent that this research is successful, it will enable people who are deaf to achieve substantially improved speech perception, speech production, and overall language competence. In addition, it will provide increased knowledge about the basic nature of speech communication, about the general capabilities of the tactile sense, about underlying principles for the design of displays, and about sensory substitution and human plasticity.

Progress—The research proposed in the application is divided into four parts. The first concerns methods of tactile communication that have evolved within the deaf-blind community and includes study of the Tadoma method, in which speech is perceived by placing a hand on the face of the talker, and also

Tactile Signing and Tactile Fingerspelling. The second includes study of Augmented Tadoma, in which the remarkable performance achieved with Tadoma is improved by adding an auxiliary tactile display of information on tongue position, and Synthetic Tadoma, in which a simulation of Tadoma that uses an artificial talking face is used as a research tool to dissect Tadoma and evaluate its components. The third compares artificial speech-reception aids that present short-term spectral information by means of homogeneous arrays of tactile stimulators. A variety of such aids are evaluated using common experimental procedures and subjects, and attempts are made to interpret results in terms of speech-parameter resolution and tactile psychophysics. The fourth involves basic study of encoding and display problems and is directed towards improved information transmission through the use of more effective encoding schemes and perceptually richer display systems.

Cutaneous Communication Aids for the Deaf

Moise H. Goldstein, Jr.

Johns Hopkins University, Baltimore, MD 21218

Sponsor: National Institutes of Health

Purpose—The goal of the research is to provide a wearable vibrotactile speech communication aid for prelingually, profoundly deaf children. The proposed work aims to achieve a design which uses a single or a few channels. A primary function of these aids shall be acquisition and enhancement of lipreading skills.

Three projects are proposed. Project I is a systematic study of candidate transformations between FO and single channel vibrotactile stimulation. Results will be incorporated in a long-term evaluation of aided lipreading by hearing, "artificially deafened," young adults. In Project II, current microprocessor technology will be used to achieve a several-channel aid that presents FO and additional segmental information, with again, evaluation of

aided lipreading. Project III is a model of the auditory periphery that will be a basis for design of a superior acoustic signal processor for aids for the deaf. The model is a computer simulation of the auditory periphery, from acoustic input to representation of temporal-spatial characteristics of neural firing by the population of auditory nerve fibers. It will include the neural coding of speech sounds as revealed in experimental work at this University.

The proposed research is important for individuals whose hearing loss is such that they are unable to derive significant speech information from the auditory channel. Electrical stimulation of the cochlea (implant) is gaining increasing attention as an aid for this population. For the post-lingually deaf adult, an implant is often beneficial; although only in very

rare cases does it provide reception without lipreading. It is critical at this time (as young children are having the expensive and traumatic implant opera-

tion), that progress be made in devising wearable vibrotactile aids that provide a reasonable alternative.

Rehabilitation Strategies for the Hearing Impaired

Harry Levitt; Nancy M. McGarr; Arthur Boothroyd
CUNY Graduate School, New York, NY 10036

Sponsor: National Institutes of Health

Purpose—Rehabilitation strategies for the hearing impaired will be developed and evaluated. Strategies for speech and auditory training of hearing impaired children and adults will be considered. The impact of tactile and visual sensory aids on learning rates will be investigated and new types of sensory aids will be developed including computer-simulated experimental hearing aids and wearable multichannel

tactile displays. Methods of rehabilitation training for cochlear implant recipients will be developed and evaluated. Analytic and global methods of training will be compared. Comparisons with tactile aids and conventional hearing aids will also be undertaken. The proposed research should result in improved rehabilitation techniques for a wide range of hearing impairments and methods of intervention.

Reading and Writing Skills in the Congenitally Deaf

Donald F. Moores and Ann E. Geers

Gallaudet College, Washington, DC 20002 and Central Institute for the Deaf, St. Louis, MO 63110

Sponsor: National Institutes of Health

Purpose—The purpose of this procurement is to study two different groups of congenitally deaf individuals: those trained via Total Communication; and those exposed to American Sign Language from early development. The contractor has access to a large number of congenitally deaf adolescents who received their early language training through one of these two approaches. Collaboration will occur between the National Institute of Neurological and

Communicative Disorders and Stroke (NINCDS), the contractor, and another institution chosen to study the Oral Approach. The institution will select, design, and construct standardized and experimental test procedures. The main objective of this project is to identify the factors related to the outcome of reading and writing training within each of the three approaches.

Factors Predictive of Reading and Writing Skills in the Congenitally Deaf

R.F. Raubertas

National Institute for Neurological and Communicative Disorders and Stroke, National Institutes of Health, Bethesda, MD 20892

Sponsor: National Institutes of Health

Purpose—This project consists of the statistical and data management aspects of a Communicative Disorders Program contract. Tasks include design of data collection and monitoring procedures, and statistical analysis of study data. The study will examine factors that may be associated with development of

reading and writing skills in the congenitally deaf. Study subjects will comprise three groups of deaf 16- to 17-year-olds, with 65 subjects in each group. Each group will include only subjects who received their preschool language training through one of three approaches: aural-oral, total communication,

and American Sign Language. Data will be collected on the audiologic, familial, and educational background of the subjects, and on their present language skills. These data will be examined for their asso-

ciation with present reading and writing skills of the subjects. A pilot study has been completed and the main data collection phase is now in progress.

Development of a Wearable Vibrotactile Aid—Phase II

Brian L. Scott

Scott Instruments Corporation, Denton, TX 76205

Sponsor: National Institutes of Health

Progress—The major concern of the Phase I feasibility study was the design of a wearable vibrotactile array. The proposed design consists of seven piezoelectric vibrators with all electronics and vibrators in one package, and the power supply in a second package. Each package measures approximately 2 1/4 inches × 6 1/2 inches × 3/4 inch and is designed to be worn on the forearm of an adult or on the thigh of a small child. Each vibrator will have a separate filter and driving circuit associated with it to allow for the investigation of various coding schemes. Phase II development is divided into four stages: 1) construct breadboard devices with three

different coding schemes; 2) evaluate the bench models on four functionally deafened and four profoundly deaf adult subjects and select one of the coding techniques; 3) construct twelve wearable units (engineering prototypes); and, 4) field test the wearable units on six additional profoundly hearing impaired adults and contrast their performance with six non-aided control subjects. It is anticipated that Phase II development will result in a production ready vibrotactile aid for the profoundly hearing impaired with enough inherent flexibility to support alternative speech coding strategies.

The Role of the Haptic System in Communication

Carl E. Sherrick

Princeton University, Department of Psychology, Princeton, NJ 08544

Sponsor: National Institutes of Health

Purpose—In continuing the study of the conditions under which tactile patterns are most accurately and speedily recognized, this project is aimed at problems of both a basic and applied character. On the basic side, the problem of suitability of different skin areas for information processing persists, and this will be taken up in the grant period by direct attack. Selected body sites will be examined in both hearing and deaf populations for standard psychophysical functions, including, but not restricted to, absolute and differential thresholds for intensity and rate, spatial and temporal limens for pulses, magnitude estimation for intensity, and pattern recognition at various levels of complexity.

Further work on the problems of pattern recognition will be done using the locally constructed tactile matrices for the palm and thigh, and the

Optacon fingertip display recently acquired. Comparisons among these areas for a variety of processing capabilities are now possible, including growth of loudness with increasing number of vibrators, and the problem of pattern discrimination with increasing communality of elements between pairs.

There will continue to be an analysis of the saltation effect, discovered in this laboratory. Of special interest is the variation of the apparent position of the saltatory phantom with repeated exposure found in the visual system, and to be searched for in the cutaneous sense. In addition, the primary determinants of the degree of saltatory leap, viz., locus, time, and intensity, will be examined for their relative influence on saltation in selected body sites.

For some time, it has been the orientation of the

Princeton Cutaneous Project to attempt to balance the basic and applied aspects of empirical inquiry. The comparative fidelity of transmission of speech information by single- and multi-channel vibrators is an applied research effort of the laboratory that serves to supply information to developers and other investigators, while at the same time presenting the investigators of this project with questions that may

lead to basic research work. The aim and hope of this approach is to serve the medical sciences with two hands, so to speak: providing the basic information on normal mechanisms of information processing by the skin, while suggesting means by which the mechanisms may replace those in other senses that are undeveloped or lost.

Development of a Cochlear Prosthesis

Blair F. Simmons

Division of Otolaryngology, Stanford Medical Center, Stanford, CA 94305

Sponsor: National Institutes of Health

Purpose—The objective of this project is to create hearing and at least limited speech comprehension in totally deaf persons by electrical stimulation of the auditory nerve. Deaf human volunteers receive multi-electrode implants within the inner ear. Basic psychophysical stimulation experiments measure the range of auditory percepts for each electrode and this data is then used as design criteria for the

development of computer-generated “speech processors” or acoustic feature detectors. The processors so developed are used to code speech sounds for electrical stimulation. Concomitant with this human research are animal experiments verifying the safety, tissue tolerance, and other features helpful and necessary for the human research.

Wearable Multipoint Opto-Tactile Transducer for the Deaf or Blind

Javier A. Valenzuela

Creare, Inc., Hanover, NH 03755

Sponsor: National Institutes of Health

Purpose—The purpose of the work is to assess the feasibility of developing a wearable multipoint opto-tactile transducer for the deaf or blind by building and evaluating a desk-top, laboratory version of the transducer. The objectives will be accomplished by: 1) reviewing technical literature on opto-tactile perception; 2) designing and fabricating a laboratory

laser-tactile transducer; 3) characterizing and testing the response of the skin to the transducer stimulation; 4) identifying the technical developments needed to fabricate the transducer (if the tests show that optical stimulation is feasible); and, 5) reporting all results of the work in a final report.

Basic and Applied Studies of Tactile Perception

Janet M. Weisenberger

Central Institute for the Deaf, Research Department, St Louis, MO 63110

Sponsor: National Institutes of Health

Purpose—The proposed research combines basic and applied laboratory studies with clinical and educational approaches to provide new information about the basic abilities of the tactile system and

the design and evaluation of tactile aids for speech perception of deaf persons.

In basic studies, the temporal properties of the tactile system are outlined using amplitude-modu-

lated stimuli and masking paradigms with vibratory stimulus presentation. Knowledge of these temporal abilities, in addition to their basic research interest, should prove useful for the design of effective tactile aids.

In applied laboratory, clinical and educational trials, three different types of experimental tactile aids will be evaluated. First, studies will continue with a single-channel vibrotactile aid worn on the chest by very young deaf children, to determine whether the aid will improve their ability to attend to and produce sounds. Second, a binaural two-

channel earmold vibratory stimulator will be tested with adults for its potential as a speech aid, both alone and as part of a hybrid auditory-tactile aid. Finally, the effectiveness of multichannel (16 or more) vibratory aids in improving the understanding of speech and the accuracy of a child's own speaking will be evaluated with deaf children enrolled in the CID school. Information from these studies should determine the situations in which each type of aid might be useful, and also point out needed improvements in the design of each kind of aid.

C. Speech Impairment

1. Hearing Related

Measurement and Prediction of Benefit from Amplification

Robyn M. Cox, Ph.D.; Kay M. Pusakulich, M.A.; Genevieve C. Alexander, M.A.; Christine Gilmore, M.A.
Memphis Speech and Hearing Center, Memphis, TN 38104

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The objective of this 2-year project is to develop and validate a test of intelligibility of everyday speech called the Connected Speech Test (CST). The project plan calls for four major experimental phases: 1) investigation of the intelligibility characteristics of a typical talker and selection of a typical talker to record the initial pool of test items; 2) generation and evaluation of the initial pool of CST test items; 3) generation of final CST test forms; and, 4) evaluation of final CST test forms.

Progress—In the past year, phases 2 and 3 have been completed. In phase 2, 72 passages of connected speech were audio-visually recorded on optical disk by the talker selected in phase 1. Twenty-five key words in each passage, five in each of five categories of difficulty, were empirically determined. In accomplishing this, the number of test passages was reduced to 57. In phase 3, 40 hearing-impaired subjects, divided into four groups according to hearing loss, provided intelligibility data for the key words in each of the 57 test passages.

Preliminary Results—A version of the CST for nor-

mal hearers was defined. This test consists of 48 test passages of equal intelligibility. The performance-intensity slope is 12 rationalized arcsine units (rau)/dB signal-to-babble ratio. For pairs of scores, each based on mean performance across four randomly-chosen passages, the 95 percent critical difference is about 14 rau.

Intelligibility data from the hearing-impaired subjects were analyzed to determine whether scores obtained for a passage were significantly related to the proportion of particular phonetic categories (e.g., voiced plosives) in the key words. Results indicated that some groups of subjects did reveal significant relationships. Consequently, the 48 passages were divided into 24 pairs with all pairs equalized in the proportion of sounds (in scoring words) in the affected categories. The resulting test consists of 24 sets of 2 passages each. On average, all sets are equally intelligible for hearing-impaired listeners. For pairs of scores, each based on mean performance across three randomly-chosen sets of passages, the 95 percent critical difference is about 15 rau.

Future Plans/Implications—In phase 4, 24 additional

hearing-impaired subjects will audit the final form of the CST. Scores will be analyzed to determine equivalence and reliability data and the performance-intensity function for the final test.

Publications Resulting from This Research

Intelligibility of Average Talkers in Typical Listening Environments. Cox RM, Alexander GC, Gilmore C, *Journal of the Acoustical Society of America* 81:1598-1608, 1987.

Development of the Connected Speech Test (CST). Cox RM,

Alexander GC, Gilmore C, *Ear and Hearing*, 1987 (in press).

Composite Speech Spectrum for Hearing Aid Gain Prescriptions. Cox RM, Moore JN, *Journal of Speech and Hearing Research*, 1987 (in press).

Intelligibility of Average Talkers in Typical Listening Environments. Cox RM, Alexander GC, Gilmore C, Pusakulich KM, presented at the National Convention of the American Speech-Language-Hearing Association, 1986.

Development of the CST for Measuring Hearing Aid Benefit. Cox RM, Alexander GC, Gilmore C, Pusakulich KM, accepted for presentation at the National Convention of the American Speech-Language-Hearing Association, 1987.

Computerized Treatment of Acquired Reading Disorders: Treatment of Alexia and Agraphia

Leslie J. Gonzalez Rothi, Ph.D.

Audiology and Speech Pathology, Veterans Administration Medical Center, Gainesville, FL 32602

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is threefold. First, to develop therapy tasks that are suitable to improve deficient reading strategies associated with the lexical or phonological routes of single word reading: to computerize these tasks and assess the efficacy of the treatment protocols for patients with alexia with agraphia. Second, to develop a second level of tasks utilizing stimuli of greater than one-word length and assess the efficacy of using both level 1 and 2 tasks for cases of alexia without agraphia. Third, to develop therapy tasks suitable to improve deficient spelling strategies associated with lexical or phonological routes of spelling: to computerize these tasks, and assess the efficacy of the treatment protocols for patients with agraphia.

Progress—All treatment tasks have been designed and reading levels 1 and 2 treatment tasks have been computerized. As of August 1987, computerization of the spelling tasks were completed. We have thus far completed treatment protocols on 20 patients on level 1 reading and three patients on level 2 reading tasks. Treatment protocols for the spelling tasks were begun in August 1987.

Preliminary Results—No group data will be analyzed until all subjects have completed the projects. However, a number of single case studies have been reported as part of, or adjunct to, this research program (see below).

Future Plans/Implications—As our knowledge of normal reading and spelling expands, the models change as to the corresponding predictions about reading and spelling abnormality. The distinctions between lexically-derived and nonlexically-derived phonology, as well as nonlexically-derived meanings of written material, allow for expansion of our model from a dual route to a 3-route model. New treatment tasks will need to be developed to follow these distinctions for more specific remediation.

Publications Resulting from This Research

Isolated Lexical Agraphia. Rothi LJG, Roeltgen DP, Kooistra C, *Brain and Language* 30:181-190, 1987.

Phonological Alexia with Optic and Tactile Anomia: A Neuropsychological and Anatomical Study. Rapcsak SZ, Rothi LJG, Heilman KM, *Brain and Language* (in press).

Treating Surface Dyslexia in A CHI Patient. Moss SM, Rothi LJG, *Journal of Clinical and Experimental Neuropsychology* (in press).

Presentations

Deep Dyslexia in a Wernicke's Aphasia. Fleet WS, Raade A, Rothi LJG, Heilman KM, *Academy of Aphasia*, Nashville, TN, 1986.

A Neuropsychological Approach to Aphasia Rehabilitation. Rothi LJG, *The 12th Annual Course in Behavioral Neurology and Neuropsychology*. The Florida Society of Neurology, Orlando, FL, 1986.

Treatment of Alexia and Agraphia in Adult Brain Damaged Patients. Rothi LJG, *The 12th Annual Course in Behavioral Neurology and Neuropsychology*. The Florida Society of Neurology, Orlando, FL, 1986.

Hemispheric Specialization for Writing in Right-Handers. Mack

L, Heilman KM, Rothi LJG, *International Neuropsychological Society*. Washington, DC, 1987 (Abstract, *JCEN*, 9:31, 1987).

Computerized Treatment of Alexia Without Agraphia: A Case Report. Moss SE, Rothi LJG, *International Neuropsychological Society*, Washington, DC, 1987 (Abstract, *JCEN*,

9:39, 1987).

A Six-year Follow-up Study of Language and Cognitive Development After a Left Hemisphere Infarct in a 9-Year-old-Girl. Voeller K, Rothi LJG, Arnus J, *International Neuropsychological Society*, Washington, DC, 1987 (Abstract, *JCEN*, 9:40, 1987).

Acoustic Vowel Measures Following Radiation Therapy to the Larynx

Richard W. Trullinger, Ph.D. and Dean C. Elliott, M.D.
Veterans Administration Medical Center, Augusta, GA 30910

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Often patients who have undergone radiation therapy (XRT) for laryngeal carcinoma confined to the true vocal folds, in the absence of positive neck nodes and/or metastases, are referred for voice therapy because of a residual hoarse voice. Generally the hoarseness diminished over time, following the completion of XRT, but the time, course, and degree of voice change have not been documented thoroughly. The overall objective of this study, therefore, is to compare perceptual, acoustic, and physical data of such cancer patients to normal-speaking controls as a function of time.

The study will ideally investigate the following questions: 1) What is the mean spectral noise level, jitter, shimmer, and fundamental frequency associated with the sustained production of five different test vowels for each data collection, i.e., baseline, once each week for 6 to 8 weeks, and at one month intervals for one year for both groups? 2) Do the data obtained for the pathologic group differ from those obtained for the normal-speaking group? 3) Are there differences between pre- and one-year post-XRT acoustic measurements, and apparent success of the XRT as evaluated visually by the surgeon who first identified the laryngeal pathology

and perceptually by a panel of speech pathologists who often provide post-XRT management to improve voice quality? 4) Do the test vowels differ with regard to the acoustic and perceptual measures? and, 5) Can a relationship be shown among acoustic and perceptual measures and alcohol consumption, smoking behavior, dry mouth, and/or amount of radiation received?

Preliminary Results—Procurement of software necessary to the collection of the proposed acoustic vowel measurements has begun. To date, the software to retrieve spectral noise level measurements has been written. Because funding for the study was just received, only partial data have been collected on three cancer patients.

Future Plans/Implications—Completion of this study will be realized with the collection and analyses of data for 20 pathologic and 20 normal-speaking individuals. The findings will aid our decision-making process regarding voice management care of patients with small laryngeal cancers that have been treated with XRT.

Language Performance in Cleft Palate Adolescents

K. McCann (Student), B.Sc.(C.D.)
Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: Hugh MacMillan Medical Centre Student Research Award

Purpose—This research project is an extension of a pilot study investigating the receptive and expressive language skills of adolescents with cleft lip and/or cleft palate. Results of the pilot study indicate that

the language abilities of cleft palate adolescents differ significantly from age-matched adolescents in the normative population. These results support the majority of research demonstrating a delay in the

language skills of cleft palate individuals. However, a larger sample size is necessary in order to effectively examine the nature of the language deficit and to investigate further those variables which serve as early predictors of later language functioning in the cleft palate population.

Progress—Twenty male and female individuals aged

11 to 20 years old inclusive with a repaired congenital cleft lip and/or palate will participate in this study. Each subject will complete the *Test of Adolescent Language*, the "Sentence Combining" subtest of the *Test of Language Development—Intermediate* and the *Test of Nonverbal Intelligence*. Subject scores will be compared with data from the normative population.

The Use of Microcomputers in Diagnosis and Rehabilitation of Adult Aphasic Individuals

Katharine Odell, M.S.; Michael Collins, Ph.D.; Charles C. Lee, M.S.; Gregg C. Vanderheiden, Ph.D.

Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, Madison, WI 53705

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—This project involves a series of studies to investigate the feasibility of using microcomputers in the diagnosis and treatment of adult aphasic individuals. The first study compared the performance of aphasic subjects on a computerized and standard version of the Colored Progressive Matrices (CPM), a visual, non-verbal problem-solving task. The second study examined the relative efficiency with which aphasic adults use different computer input systems (i.e., keyboard, long range light pen, stylus, touch-sensitive screen, and joystick); performance on a measure of reading comprehension was compared across all interface systems. Results of that work will assist in the selection of appropriate input systems for aphasic users. Further, analysis of response characteristics using each of the interface systems will address the theoretical question of competition for cognitive resources: i.e., the degree of cognitive ability required of aphasic users to both operate the device and proceed with the test.

Another study in the series will investigate computer strategies for recognizing perseveration and self-correction attempts and will develop software to both interrupt perseveration and facilitate self-correction tendencies. The behavioral tool for this study is a computerized version of the Revised Token Test (McNeil and Prescott, 1978), a measure of auditory comprehension on which aphasic subjects are likely to display perseveration or self-correction tendencies.

Progress—*Study 1*: Comparisons of performance on

the standard and computerized version of the CPM has shown that quality of performance in terms of percentage correct and response time does not vary significantly across test versions for our samples of severely, moderately, and mildly-impaired subjects (Odell, Collins, Dirkxs and Kelso, 1985), "A Computerized Version of the Colored Progressive Matrices," in *Clinical Aphasiology Conference Proceedings 1985*, R. Brookshire (Ed.), BRK Publishers, Minneapolis, MN.

Study 2: The reading measure for this project is a multiple choice synonym-identification test, with two levels of difficulty. A different test was developed for each interface system; all tests were designed to be equivalent in grade level. Algorithms for scoring and response time data collection were devised. A Latin Square (complex) design was used for the study. Ten of the 12 subjects have been tested.

Study 3: The software routine developed for the Revised Token Test has been completed, including token movement, scoring, data collection, and speech generation algorithms. Programming algorithms for perseveration interruption and self-correction facilitation are being completed. A series of single-subject design studies using a multiple-treatments design is planned. One portion of the test will focus on perseveration and will initially involve two subjects; the second portion will focus on self-correction and also initially involve two subjects.

Future Plans—Extension of Study 2 to compare the mouse device and other access systems is being considered.

The Acquisition of Morphological Processes in American Sign Language (ASL)

Ursula Bellugi

Salk Institute for Biological Studies, San Diego, CA 92138

Sponsor: *National Institutes of Health*

Purpose—The general objective of our research is to study the human capacity for language. We aim to investigate to what extent the overall form and organization of language is determined by the articulatory and perceptual modality in which it has developed, and to what extent these represent more fundamental aspects of human cognition. As a research tool, we study American Sign Language (ASL), the system of hand signs developed by deaf people in the absence of speech. We find that ASL differs dramatically from English and other spoken languages in some of the mechanisms by which its lexical units are modified. For the form of its inflectional and derivational processes, the mode in which the language develops makes a crucial difference.

In this grant we propose to study the acquisition of three contrasting subsystems of ASL: 1) The system of morphological processes which operate on signs, simultaneously changing or adding specifications for dimensions of movement to the root form of the sign; 2) compounding processes which

are essentially sequential combinations of signs, bound together by particular rhythmic properties which differentiate them from phrases; and, 3) spatial indexing, a system which includes the establishment of loci for non-present referents in the signing space between signer and addressee, and anaphoric reference by pointing or by inflection of verb. Detailed longitudinal studies of spontaneous mother/child interactions on videotape are augmented with experimental interventions. We have chosen to investigate the acquisition of specific aspects of the grammar, selected so that some are most like and some are most unlike comparable processes in spoken language. In the process, we investigate the acquisition of some of the most distinctive aspects of signed languages: its conflation, its simultaneity and its structured use of space. The comparison of the acquisition of signed and spoken languages becomes a privileged ground for testing hypotheses about the mechanisms that determine language structure.

Electrically Controlled Talking Tracheostomy Systems

Daniel J. Koester, B.S.; Simon P. Levine, Ph.D.; Ronald L. Kett, M.S.

Rehabilitation Engineering Program, Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center, Ann Arbor, MI 48109

Sponsor: *Rehabilitation Engineering Program, Department of Physical Medicine and Rehabilitation, University of Michigan*

Purpose—An individual can become ventilator-dependent due to neuromuscular disease, high-level spinal cord injury, or any other condition that seriously reduces respiratory function. For those requiring long-term ventilation, a tracheostomy tube is surgically implanted into the trachea below the larynx. Cuffed tracheostomy tubes are used to insure that adequate ventilation parameters are maintained and to protect the inner airways. Providing a means of communication for these patients is crucial to their medical as well as their psychological well-being.

A commonly-used method to provide verbal expression for patients using a tracheostomy tube,

is to partially deflate the cuff, allowing air to flow up across the vocal cords. Another method employs a specially-designed "talking tracheostomy" tube which has an additional small gauge air line running along its curved surface and ending just above the cuff. The external end of this air line is connected to a source of compressed air that is regulated to produce audible speech (approximately 5 liters/minute). A "tee" in the air line provides a port to control the air flow to the vocal cords. Air flow escapes out of the control port until covered by a finger to direct air through the air line to the vocal cords. It is the inability to close this control port that prevents quadriplegics from being able to in-

dependently actuate their voice. Several systems for independent actuation of the talking tracheostomy systems have been developed.

Progress—Two basic designs have been developed to allow independent voice control: 1) an electro-mechanical solenoid to control flow from a compressed air source; and, 2) an air compressor which can be turned on and off to supply regulated air to a talking tracheostomy tube. These systems have been designed for either bedside use or in a portable wheelchair-based arrangement.

The compressed air system consists of a 110 VAC normally closed solenoid valve placed directly in-line with a compressed air source (such as a hospital room wall outlet). A humidifier bottle is placed in the line to moisten the air before it enters the trachea. The air control port is eliminated as air passage only occurs when the valve is activated by a switch. The solenoid valve can be activated through a momentary switch (non-latched, time-latched, or latched), or an environmental control unit.

The solenoid system has been made transportable through the use of a small pressurized air tank and a 12 VDC solenoid valve powered by ventilator or wheelchair batteries. Designs for mounting tanks, ventilator, and battery to either a manual or electric wheelchair have been developed. One drawback of pressurized tanks is that they must be refilled. A 12 VDC compressor has been used in place of an air tank but produces considerable noise. Containers with high density foam and filters on the inlet port have been designed for noise reduction. A humidifier bottle on the outlet port further reduces noise.

Preliminary Results—The solenoid valve systems have worked with good success in both bedside and portable configurations. Regulation of air pressure from hospital wall outlets (to 25 psi) has been required, because pressures over 50 psi damage the flow meters controlling air flow to the vocal cords. In addition to its applicability to wheelchair-portable systems, the compressor-based system has been used in a home bedside unit. Minor electronic modifications were required: in this case, to permit activation of the system through an environmental control unit. The ECU provided the 12 VDC and the latching switch functions needed to operate the system.

Future Plans/Implications—These systems have been extremely successful in allowing patients to independently control their talking tracheostomy systems. Independent voice control has greatly enhanced communication for these individuals. Future options will include improved mounting systems, air compressors, and other system components. Options for more automatic control of these talking tracheostomy systems (i.e., one that senses speech initiation) are also being considered.

Publications Resulting from This Research

- Independently Activated Talking Tracheostomy Systems for Quadriplegics.** Levine SP, Koester DJ, Kett RL, *Archives of Physical Medicine and Rehabilitation*, 1987 (in press).
- Self-Activated Talking Tracheostomy Systems for Quadriplegics.** Koester DJ, Levine SP, Kett RL, Kluin KJ, *Proceedings of the 9th Annual RESNA Conference* 6:299-301, Minneapolis, MN, June 1986.

Speech Transmission Laboratory Reports

The Royal Institute of Technology

Department of Speech Communication and Music Acoustics, S-100 44 Stockholm, Sweden

Sponsor: Swedish Board for Technical Development; The Bank of Sweden Tercentenary Foundation; The Swedish Natural Science Research Council; The Swedish Council for Research in the Humanities and Social Sciences; The Swedish Telecom; The Swedish Ministry for Social Affairs; The Swedish Institute for the Handicapped; The Swedish Council for Planning and Coordination of Research; Knut och Alice Wallenbergs Stiftelse; Nordiska Nämnden för Handikappfrågor; Stiftelsen Tysta Skolan; Telefonaktiebolaget L M Ericsson

The following reports summarize work conducted at the Speech Transmission Laboratory in the areas

of speech production, speech synthesis, musical acoustics, and speech and hearing defects.

Nonlinear Interaction in Voice Production

Qiguang Lin

Progress—A source model taking the acoustic interaction into account was developed. As an integrated component, the approach to deriving a lumped-parameter representation of the VT load is also outlined. To evaluate the model, a selective-inverse-filtering technique is utilized. A comparison is made between interactive and linear source conditions. We find that the interactive source model can, to a certain extent, reproduce the effect that higher

formant amplitude maxima tend to synchronize with F1 amplitude maxima, viz., indicating an F1/F0 dependency. We have also studied the skewing of glottal flow and its overlaid ripples. All of these aspects are known to occur in human speech. Thus, the present model is closer to the mechanism of true speech production and should accordingly contribute to the development of high quality synthesis.

Glottal Source—Vocal Tract Acoustic Interaction

Gunnar Fant and Qiguang Lin

Progress—Recent developments within our group of voice source—vocal tract acoustic interaction placed special emphasis on non-linear superposition phenomena, i.e., how the excitation within a period is dependent on the past history of vocal tract oscillations and their residual components within

the transglottal pressure. A study of breathy phonation shows that constant leakage affects the voice source slope less than does the dynamic leakage in terms of a residual closing phase. A simulation of a female voice source is attempted.

Speech Technology for the Visually Impaired: The Swedish Perspective

Björn Granström

Progress—Fundamental speech research at the Department of Speech Communication and Music Acoustics, KTH, has lead to a multilingual text-to-speech system and a speech recognition device. Both are presently put to use by the visually impaired.

To date, over five hundred text-to-speech systems have been delivered, most of them to applications for the visually impaired. Some of these applications

include software for screen access, reading machines and a radio-distributed daily newspaper experiment. In some applications, simple speech coding techniques suffice, as in a cuing system that recently has been successfully introduced.

Work on present and future research topics, that will lead to improved speech technology aids for visually impaired persons, is planned.

Relationship Between Changes in Voice Pitch and Loudness

Patricia Gramming; Johan Sundberg; Sten Ternström; Rolf Leanderson; William H. Perkins

Progress—The change in mean fundamental frequency accompanying changes in loudness of phonation during reading was analyzed in nine professional singers, nine nonsingers, and in ten male and ten female patients suffering from vocal fatigue and/

or functional dysfunction. The subjects read discursive texts with LP-filtered noise in earphones, and some also voluntarily varied vocal loudness. Also, the healthy voice subjects phonated as softly and as loudly as possible at various fundamental fre-

quencies throughout their pitch ranges, and the resulting mean phonetograms were compared. The mean fundamental frequency was found to increase by between 0.2 and 0.6 semitones per dB equivalent sound level. No great differences were found between these subject groups, although the singers

were found to vary their mean fundamental frequency more than the nonsingers. It is possible to explain the voice pitch changes as the passive results of the changes of subglottal pressure applied in order to vary sound level of phonation.

Long-Term-Average Spectrum Analysis of Phonatory Effects of Noise and Filtered Auditory Feedback

Johan Sundberg; Sten Ternström; William H. Perkins; Patricia Gramming

Progress—Using long-term-spectrum (LTAS) analysis of fluent speech, the effects of speaking in noise and of speaking with differently filtered auditory feedback as well as of voluntarily changing vocal intensity were analyzed in nine male adult singers and nonsingers. Three values in the LTAS were analyzed: the level of the main peak near 500 Hz, of a secondary peak near 2000 Hz and at the average fundamental frequency. The level at 500 Hz was highly correlated with the equivalent sound level, with the average fundamental frequency and with the level of the peak near 2000 Hz. The singers were found to produce a higher sound level than the

nonsingers under all conditions, and their voices contained stronger high-frequency components. Also, unlike the nonsingers they reduced vocal intensity when reading in silence with enhanced high-frequency components in the auditory feedback. The LTAS effects of noise and of auditory feedback filtering was found to be similar to those of the voluntary changes of vocal intensity for both singers and nonsingers. When the high-frequency components of the auditory feedback was enhanced during reading in noise, both subject groups reduced vocal intensity.

Some Effects of Cochlear Implantation on Speech Production

Anne-Marie Öster

Progress—A new method for the treatment of acquired total deafness in adults has been under probation in Sweden since 1983. The Vienna Cochlear Prosthesis is an extra-cochlear system comprising a single-channel implant with its active electrode placed in the round-window niche. The device functions on the basis of electrical stimulation of the cochlear nerve.

The present study involved acoustical analyses of fundamental frequency of two patients' recorded readings of a familiar text consisting of 89 words and an unfamiliar text of 56 words. The recordings

were made pre-implant and post-implant after 1, 3, 6, 12, and 24 months. We have also made recordings of the patients when they read the text without and with the implant.

The analyses made included the speech rate, phonation time as well as the mean and the standard deviation of the fundamental frequency. The results were shown in forms of FO-histograms. The main effect found was an improvement in FO-control, which means a lowering in mean FO and a more normal FO-distribution. A shift towards a more normal rate of articulation was also found.

C. Speech Impairment

2. Aphasia

Promoting Generalized Language Use: An Analysis of Treatment Strategies

Patrick J. Doyle, M.A.; Howard Goldstein, Ph.D.; Michelle Bourgeois, M.S.; Karen Nakles, M.A.
Veterans Administration Medical Center, Pittsburgh, PA 15206

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The challenge in the rehabilitation of the adult with acquired aphasia is to provide interventions that reliably and efficiently result in the acquisition of functional communication skills that endure over time and are performed across the variety of conditions imposed by the natural environment. Thus, the concept of generalization or transfer of treatment effects is a fundamental concern of the clinical aphasiologists.

Traditionally, the process of generalization of learned behaviors was expected to occur as a natural consequence of the acquisition process. This may account for the relatively few studies in which programming was specifically designed to promote generalization. Unfortunately, many intervention programs that produce excellent effects under treatment conditions often fail to result in similar behavioral changes under more natural conditions. The purpose of our program of research is to identify treatment variables that will enhance the ability of aphasic adults to generalize learned language behaviors to natural conversational contexts.

Progress—In a recently completed study, four neurologically stable adults with Broca's aphasia were trained to use the communicative function of requesting information. The treatment program employed five variables which we hypothesized would enhance generalization. These were: 1) the use of multiple trainers; 2) selection of the target behavior based upon communicative function rather than structural form; 3) reinforcement and shaping of subject-initiated utterances; 4) reinforcement of relevant variations of the target response; and, 5) systematic manipulation of the stimulus conditions employed during training to approximate those en-

countered in natural conversational contexts. As our dependent measure, each subject had 36 5-minute conversations with unfamiliar peer volunteers who were blind with regard to the purpose of the study and the target behavior under investigation. The effects of treatment were evaluated by employing the single case experimental design of a multiple baseline across behaviors and subjects. This design allows one to examine changes in the level of responding of treated and untreated behaviors across baseline, treatment, and maintenance phases of the study, while inherently controlling for threats to internal validity.

Results—The results of this investigation revealed that all subjects acquired the target behavior under training conditions and that three of the four subjects were able to use the behavior in conversational interactions with unfamiliar peer volunteers at levels well above their baseline performance. These results indicate that aphasic adults, similar to those described in this study, can generalize learned language behaviors to extratherapy contexts and that the manner in which language responses are trained will effect the degree to which generalization occurs.

Future Plans/Implications—Our future research will focus on the identification of those variables that are both necessary and sufficient for the process of generalization of treatment effects in aphasic adults.

Publication Resulting from This Research

Experimental Analysis of Syntax Training in Broca's Aphasia: A Generalization and Social Validation Study. Doyle PJ, Goldstein H, Bourgeois MS, *Journal of Speech and Hearing Disorders*, 52:143-155, 1987.

An Experimental Analysis of Response Elaboration Training in Aphasia

Kevin P. Kearns, Ph.D., and Gail Potechin, Ph.D.

Veterans Administration Medical Center, Audiology/Speech Pathology Service, North Chicago, IL 60064

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The primary purpose of this project is to examine the effectiveness and generality of Response Elaboration Training for aphasia (Kearns, 1985). This procedure is a form of divergent semantic language intervention designed to facilitate an increase in the quantity and variety of verbal responses produced by patients with nonfluent aphasia. The emphasis in Response Elaboration Training (RET) is on facilitating an increase in the amount of information contained in patients' verbalizations. Unlike more didactic training programs, specific lexical items are not targeted for intervention during RET. Rather, spontaneous, patient-initiated utterances are systematically chained together to elicit more elaborate verbal responding.

A within-subject experimental design (i.e., multiple baseline across behaviors and subjects) was used to explore two key questions: 1) Will RET facilitate an increase in the amount of information (number of content words) produced by nonfluent aphasic subjects within the treatment setting? and, 2) Will RET result in generalization of more elaborate responding to untrained stimuli, settings, and individuals?

Progress—To date, four nonfluent aphasic subjects have completed the training protocol and social

validation data have been collected on ten age-matched normal subjects. The results for three experimental subjects replicated our initial findings. RET facilitated an increase in the number of content words produced in response to training and generalization stimuli. Generalization of training effects to spontaneous interactions, novel settings, and individuals, although somewhat variable, was also found.

The generality of RET was further explored by using the procedure with a nonverbal aphasic-apraxic patient in an attempt to train him to communicate through drawing. This cross-modality replication was successful. The patient developed an elaborate nonverbal (drawing) communication system on structured tasks and generalization occurred to untrained stimuli, settings, and people.

Preliminary Results—Our preliminary data support the contention that RET is an effective procedure for facilitating increased production of informational content for nonfluent aphasic patients. The results of generalization testing have also been encouraging. Additional data are being collected on RET and future efforts will compare the results of this procedure to more didactic training approaches.

Drawing: Its Use as a Communicative Aid with Aphasic and Normal Adults

Jon G. Lyon, Ph.D.

Rehabilitation Medicine, Veterans Administration Medical Center, Reno, NV 89520

Sponsor: VA Rehabilitation Research and Development Service

Purpose—For adults who incur a cerebral stroke that results in the loss of speech due to a linguistic deficit (aphasia), approximately one-half will never reacquire adequate verbal skills to communicate their daily needs. That is, although they may understand simple requests, statements, or commands and appear to know the basic concepts to be expressed, they are unable to retrieve and order the necessary verbal symbols to do so. The purpose of

this investigation was to determine whether drawing might serve as an alternative form of expression which, in combination with existing communicative skills, would permit the successful completion of such communiques. In addition, a control group of normal adults was included to determine how readily nonbrain-damaged adults could draw communicatively when restricted to comparable levels of verbal and handedness use.

Progress—Eight chronic, severe, Broca's aphasic adults and eight, normal non-brain-damaged adults were studied for their ability to communicate a variety of information (objects, actions, sequences, questions, and solutions to simple problems) to a naive interactant. For aphasic adults, baseline measures were obtained for their ability to communicate such information to a naive interactant within a three minute period using drawing and, on a separate occasion, without the use of drawing. Thereafter, they were enrolled in a three month "drawing" treatment program which stressed two facets: 1) refinement of drawing skills needed to augment communication; and, 2) instruction of interactants in how to extract information from drawings. Following the treatment period, baseline measures were re-administered. Performance on baseline measures were judged on an eight-point ordinal scale which delineated accuracy, completeness, and promptness of response. Normal adults did not require a treatment period in that they drew and communicated beyond predetermined criteria levels on initial baseline measures whether using dominant or nondominant hand and being restricted to a verbal "yes or no" with interactants.

Results—Aphasic adults communicated information significantly better to interactants when drawing

was used than when it was not used even prior to treatment. Further significant gains occurred for these subjects following the three-month treatment period.

Future Plans/Implications—These findings support the premise that drawing does serve as an effective communicative alternative for expressively restricted aphasic adults. Based on these findings, the current investigator is completing a Merit Review submission to look at the use of drawing in acute, expressively restricted aphasic adults when compared to traditional treatment (pantomime) techniques in four separate VA Medical Centers.

Publications and Presentations Resulting from This Research

Drawing: Its Communicative Significance for Aphasic Adults. Lyon JG, Helm-Estabrooks N, In C. Hagen (Ed.), *Topics in Language*, Rockville, Maryland, Aspen Systems Corp., Oct. 1987.

Drawing: Its Value as a Communicative Aid for Aphasic and Normal Adults. Lyon JG, Sims E, *Journal of Speech and Hearing Disorders*, (in press).

Drawing: Evaluation of Its Use as a Communicative Aid with Aphasic and Normal Adults. Lyon JG, Sims E, Second International Aphasia Rehabilitation Congress, Goteborg, Sweden, June 1986.

Drawing: A Communicative Aid for Aphasic and Normal Adults. Lyon JG, Sims E, *American Speech-Language-Hearing Convention*, New Orleans, LA, November 1987.

Computer-Aided Visual Communication for Severely Impaired Aphasics

Richard D. Steele, Ph.D.; Michael Weinrich, M.D.; Maria K. Kleczewska, M.S./C.C.C.; Gloria S. Carlson, M.S.
Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Rehabilitation Research and Development Service

Purpose—The purpose of this project is to research and develop a graphically oriented, computer-based alternative communication system for chronic, severely aphasic individuals. It is called the C-VIC (for Computer-Aided Visual Communication) system. It is to draw on selected subjects' demonstrated abilities to identify graphic objects, arrange them according to specified conventions, assign meanings to the resulting structures, and use them reliably to support performance and communicate about many conventional transactions in activities of daily living. Four major questions will be answered by this project. 1) Specifically, which aphasic individuals and populations can benefit from the device, when,

and how? 2) What graphically encoded communicative abilities can be tapped or developed to help our severely aphasic patients, and what is their relationship to natural language? 3) Which activities of daily living can benefit from such communicative support, and how? 4) Can artificial intelligence modules assist aphasic individuals in using this assistive device, and how?

Progress—Investigators have pursued several mutually reinforcing lines of activity. These include:

1) Designing, implementing, and modifying successive versions of the C-VIC interface on the Macintosh computer, and gaining experience in

patient training on successive interface versions as they become available.

2) Selecting candidate users from a population of severely aphasic individuals of differing etiologies and deficit profiles; providing them training in the use of the system and monitoring their progress; and periodically assessing their communicative abilities in different modalities using standard assessment tools or their modifications (when necessary).

3) Designing and conducting single-subject controlled experiments with aphasic subjects, in order to: a) analyze effects of C-VIC training versus effects from equivalent speech therapy training; b) characterize patient learning, generalization, and retention on the system, and, c) probe the effect of differing types of graphic representations on user performance.

4) Exploring the potential for a modified C-VIC interface to be used in other promising ways, for example, as a cognitive orthosis to help aphasic persons perform new and/or complex tasks without immediate human supervision.

Results—Progress can be reported in each of the four areas identified above:

1) In interface work, we completed the programming of C-VIC Version 1.0 (card metaphor) in December, 1986, and have been using it in patient training since completion; we anticipate finishing Version 2.0 (high graphic interactivity) in December, 1987, and Version 3.0 (artificial intelligence capabilities) the following year.

2) In training, we have gained extensive experience with three globally aphasic individuals and two subjects with severe Broca's aphasia, plus some additional experience with other subjects. This training has shown several things: a) that mastery of the fundamentals of the system is within the capability of all our subjects; b) that their performance in communicative transactions using C-VIC is significantly better and more reliable than in comparable transactions using natural language; and, c) that the subjects are enthusiastic about using the system, and perform better on the computer than on the original VIC cards, despite several novel cognitive demands by the computer.

3) In controlled experimental studies, we have: a) shown circumstances under which C-VIC training produces superior results to equivalent traditional speech therapy; b) demonstrated the efficacy of

components in C-VIC training; and, c) begun answering questions on the proper representation of "verbs" within the system.

4) Finally, we have begun pilot studies to explore the potential of C-VIC type communications for guiding subjects through complex, multi-step tasks, such as baking a cake, with promising (e.g., edible) results.

Future Plans/Implications—Work is scheduled to proceed apace on each of the four fronts. Version 2.0 of the interface should be ready by the end of 1987, and we will begin training with it soon thereafter. We are already making arrangements to increase our patient pool, to gain training experience with larger numbers and types of patients. We are expanding the number and type of controlled experimental studies, as these both guide specific project decisions, and help us to document and report the efficacy of the approach. Finally, we are actively working on identifying and producing pilot data on other promising C-VIC applications to help language-impaired individuals.

Publications and Award Resulting from This Research

Representations of 'verbs' in a Computerized Visual Communication System. Weinrich M, Steele RD, Kleczewska MK, Carlson GS, Baker E, *Proceedings of the 10th Annual RESNA Conference*, 7:162-164, San Jose, CA, June 1987.

Designing a Computerized Visual Communication System for Global Aphasics, Carlson GS, Kleczewska M, Steele RD, Weinrich M, *Proceedings of the 10th Annual RESNA Conference*, 7:94-96, San Jose, CA, June 1987.

Patterns of Learning in Aphasics Trained on a Computer-Based Visual Communication System. Kleczewska M, Carlson GS, Steele RD, Weinrich M, *Proceedings of the 10th Annual RESNA Conference*, 7:157-159, San Jose, CA, June 1987.

Evaluating Performance of Severely Aphasic Patients on a Computer-Aided Visual Communication System. Steele RD, Weinrich M, Wertz RT, Kleczewska M, and Carlson GS, forthcoming in *Clinical Aphasiology*, 1987.

Prospects for a Cognitive Orthosis. Weinrich M, Steele RD, forthcoming chapter in *Advances in Neurology*, "Functional Recovery in Neurological Disease," Stephen G. Waxman (Ed.), 47:583-600, New York: Raven Press, 1988.

A Microcomputer-Based Visual Communication System for Treating Severe Aphasia. Steele RD, Weinrich M, Wertz RT, Carlson GS, and Kleczewska M, *Abstracts of the Academy of Aphasia*, 7-8, 1986.

Training Severely Impaired Aphasics on a Computerized Visual Communication System. Steele RD, Weinrich M, *Proceedings of the 9th Annual RESNA Conference*, 6:348-350, Minneapolis, MN, June 1986.

Computerized Icon-Based Communication for Aphasics. Steele RD, Weinrich M, *Proceedings of the 39th Annual Confer-*

ence on Engineering in Medicine and Biology, Baltimore, MD, 1986.

Computerized Visual Communication for Severely Impaired Aphasics. Steele RD, Illes J, Weinrich M, *Journal of Clinical and Experimental Neuropsychology*, 7(6):609, 1986.

Implementation of a Visual Communication System for Aphasic Patients on a Microcomputer. Weinrich M, Steele RD, Illes

J, and Lakin F, *Annals of Neurology*, 18(48), 1985.

1987 Special Award for Creative/Innovative Application of Information Resources Management, US Government Inter-agency Committee on Information Resources Management (IAC/IRM) Annual Competition, awarded to RD Steele and M Weinrich.

Technology Applications for Aphasia Rehabilitation: Lessons from Sweden, Poland, and The Netherlands

Richard D. Steele, Ph.D.

Various Institutes in Stockholm, Sweden; Warsaw, Poland; and Delft, Hoensbroek, Leersum, Eindhoven, Nijmegen, The Netherlands

Sponsor: VA Rehabilitation Research and Development Service; International Exchange of Experts and Information in Rehabilitation, World Rehabilitation Fund, Inc., New York

Purpose—The purpose of the trip was to study and report on current and upcoming uses of contemporary technology for aphasia research and rehabilitation in three European countries of differing political systems, economic situations, and cultural mores—Sweden, Poland, and The Netherlands—and to draw out the implications of the findings for aphasia researchers and clinicians in the United States.

Progress—The investigator used preparatory study, site visits to relevant institutions, indepth researcher/clinician interviews, and content analysis to prepare his report. Interviews aimed at establishing and assessing the particulars both of previously reported work, and as of yet unreported projects. The existence of local contacts allowed for meetings, under local sponsorship, with aphasia researchers and clinicians in a variety of settings (e.g., the Swedish Aphasia Association Headquarters, the Polish Psychoneurological Institute, the Dutch Institute of Rehabilitation Research, among others). Altogether, some 40 individuals in 15 institutional settings were interviewed, with information gathered on 16 special projects of relevance in aphasia research and treatment.

The topic of technology applications to aphasia studies merits attention. In general, aphasia researchers and clinicians are not aggressively exploiting potentially useful, but still relatively novel, technologies. In this regard, they are rather focusing their attention primarily on a single one: computer-based tomography. The contents of two 1986 U.S. conference—the Academy of Aphasia, and the Clin-

ical Aphasiology Conference—are illustrative. Of 87 papers in those proceedings, only 12 (14 percent) involve innovative technological approaches, and of those 75 percent (9 papers) report on computer-aided tomography (CT, PET). While these papers make invaluable contributions to our knowledge, they also show that some available tools are being left under-utilized (e.g., database tools, statistical package tools, expert system tools, evaluation tools, and more). Given the magnitude of the tasks in aphasia research and the limited manpower, the field can ill afford such neglect.

Results—The overseas study revealed several ongoing projects that deserve the attention of aphasiologists in the United States. While many of them are aimed directly at the problems of aphasic deficits and their rehabilitation, others are not. These latter focus on research in relevant ancillary fields—problems of communication, or learning behaviors, or of device development and evaluation. Their value lies in methodologies which are being elaborated, subsequently available for adaptation and transfer to aphasia research projects. Three examples follow:

1) In Delft (Netherlands), researchers and clinicians have developed a System for Training Aphasic Patients (STAP), which is being evaluated in a three-stage, longitudinal single-subject experimental design, with some positive results.

2) In Hoensbroek (Netherlands), a psycholinguist is developing computer-based tools to analyze communicative transactions between young, language-disordered children and their caregivers.

3) In Stockholm (Sweden), the Swedish National

Board for Technical Development (STU) is funding two computer-based projects to develop therapeutic and alternative communication systems for aphasic individuals.

Future Plans/Implications—Observations from the study suggest several things. Researchers must learn more about advanced tools under development elsewhere and should establish networks for ongoing communication and mutual support. They can benefit from broadening their contacts with ancillary fields, and may have lessons to learn from foreign models for organizing, supporting and conducting

research, development and evaluation. An important practical observation is that much of the current work is tied rather closely to clinical activities: both theoretical and clinical aphasiologists can benefit from more extensive interaction and collaboration in developing, using, and evaluating contemporary technology in their projects.

Publications Resulting from This Research

Technology Applications for Aphasia Rehabilitation: Lessons from Sweden, Poland, and The Netherlands. Steele RD, *Fellowship Report to the International Exchange of Experts and Information in Rehabilitation Program*, World Rehabilitation Fund, Inc., New York, NY, May 1987.

Efficacy of Remote Treatment of Aphasia by TEL-Communicology

Gwenyth R. Vaughn, Ph.D.; Walter W. Amster, Ph.D.; John C. Bess, Ph.D.; Douglas J. Gilbert, Ph.D.; Kevin P. Kearns, Ph.D.; Amy Key Rudd, Sc.D.; Angela A. Tidwell, M.S.; Carleen F. Ozley, M.S.
Audiology-Speech Pathology Service, Veterans Administration Medical Center, Birmingham, AL 35233

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Four Veterans Administration Medical Centers participated in an investigation designed to compare the efficacy of remote treatment of aphasia by TEL-Communicology (TEL-C) with traditional Face-to-Face treatment. Those patients who met selection criteria were assigned randomly to either the traditional treatment program delivered Face-to-Face, or to the treatment program delivered by TEL-C. The patients who rejected randomized group placements were given the option of entering self-selected groups in order to receive treatment by the other delivery system. This option resulted in four groups—two randomized and two self-selected.

Progress—An evaluation battery of language measures was administered at entry, eight, sixteen, and twenty-four weeks. Neurological evaluations were given upon entry and upon completion of twenty-four weeks of treatment. All subjects received five hours of treatment a week for six months, or for as long as they remained in the study. Two groups received treatment delivered Face-to-Face; two groups had treatment delivered by TEL-C. The latter consisted of two-thirds clinician-assisted TEL-C and one-third REMATE computer-assisted TEL-C. (REMATE is an acronym for Remote Machine-Assisted Treatment Evaluation.)

Clinical data analyses. The data showed no differ-

ences between the Face-to-Face and the TEL-C groups, nor between the randomized and self-selected groups, in regard to age, education, or initial severity levels. All groups improved during the treatment period. There were few significant differences (as many as would be expected by chance), and they were all in favor of TEL-C. It appeared that Face-to-Face and TEL-C delivery of treatment were equally effective. On the Porch Index of Communicative Ability (PICA), there was a tendency for randomized subjects to approximate the estimated target levels at six months post-onset more closely than did the self-selected subjects.

Cost comparison. The cost of the delivery of the Face-to-Face treatment on this project was 191.4 percent more costly than the combined TEL-C clinician and TEL-C REMATE delivery. These costs included direct and indirect costs, telephones, and facility/patient travel costs.

Results—This project demonstrated that the combined TEL-C clinician-assisted and TEL-C REMATE-assisted delivery of a remote aphasia treatment program was as effective as that delivered by the traditional Face-to-Face delivery system. This study also showed that, on a national basis, the Veterans Administration traditional Face-to-Face delivery system in speech pathology in 1985, was

148.6 percent more costly than TEL-C clinician-assisted delivery, and 344.9 percent more costly than TEL-C REMATE-assisted delivery.

Future Plans/Implications—Because of the careful selection of subjects for the study, the size of the sample obtained was smaller than desirable. Many of the group differences failed to meet statistical significance, although the differences appeared to be clinically significant. Future studies, therefore, should be planned to increase the size of the sample. This could be done in several ways: (1) by making

the subject selection criteria less stringent; (2) by increasing the number of centers participating in the study; or (3) by increasing the length of the study. Clinical experience during the study also suggested the usefulness of TEL-C for providing information, guidance, support, and treatment information to the families of aphasia patients.

Publication Resulting from This Research

Efficacy of Remote Treatment of Aphasia by TEL-Communicology, VA Rehabilitation Research and Development Project, Audiology-Speech Pathology Service, Veterans Administration Medical Center, Birmingham, AL, September 1986.

The Influence of Mode of Stimulation on Naming Performance in Aphasia

Sarah E. Williams, Ph.D.

Veterans Administration Medical Center, Bay Pines, FL 33504

Sponsor: *VA Rehabilitation Research and Development Service (Pilot Proposal #C943-PA)*

Purpose—Naming is a language behavior of special interest to aphasiologists, since a reduction of the capacity to name seems to be almost universal in aphasia. Four major variables appear to influence the naming performance of aphasic patients: 1) the characteristics of the referent to be named; 2) the characteristics of the referent's name; 3) the type of stimulus presentation; and, 4) the situation in which naming occurs. Only recently have attempts been made to study the last variable.

The purpose of the proposed pilot study is to examine the influence of situational context (confrontation naming versus running speech) on the recall of nouns and verbs by aphasic patients when the stimuli are videotaped, rather than depicted by line drawings as in previous investigations. It is hypothesized that, with more realistic portrayals of objects and actions on videotape, results obtained will differ from those obtained in previous studies using line drawings.

The following goals will be accomplished: 1) determine the extent to which performance in confrontation naming is predictive of naming perform-

ance during connected speech for both objects and actions; 2) determine whether object and/or action naming performance is significantly different during confrontation naming versus connected speech for any syndrome(s) of aphasia; 3) determine whether performance is significantly different for any syndrome(s) of aphasia when naming objects versus actions; 4) determine the patterns of naming errors produced by each syndrome of aphasia for object and action naming; and, 5) compare the results obtained in this investigation with those obtained in earlier studies using line drawings as stimuli.

Results of this investigation will be compared to previous research findings using line drawings as stimuli to determine if the number and type of errors produced by aphasic patients varies according to the mode of stimulus presentation. In addition, the specific syndrome(s) influenced the most by mode of stimulus presentation will be identified. This will provide important information for Speech-Language pathologists who are routinely involved in the diagnosis and treatment of aphasia.

Recovery from Aphasia in Stroke

Rita S. Berndt

University of Maryland Medical School, Baltimore, MD 21201

Sponsor: National Institutes of Health

Purpose—The project proposes to obtain systematic evaluation of the course of recovery from aphasia in a population of stroke patients. The study has three specific goals. First, this project will provide extensive information on the demographic, neuroanatomical, medical, and neurolinguistic correlates of the recovery of specific language functions in aphasia. This information about prognostic factors can be used as a database for the development of on-line, computer assisted decision aids that would be of use to the neurologist in deciding questions of patient management. Second, the proposed study will evaluate the hypothesis that some language functions recover better than others. Experimental tests will be administered that allow relatively selective evaluation of distinct aspects of language comprehension (such as phoneme discrimination) and of speech production (such as syntactic complexity). Scores obtained on these measures will be used to evaluate the possibility that there are different recovery rates for particular aspects of gross

language functions such as comprehension and production. In addition to their considerable theoretical importance, the results of such an evaluation would have significant implications for the design of therapies and communication aids for the aphasic patient. Third, the study proposed here will furnish data for testing hypotheses concerning the functional components that underlie the major aphasic syndromes.

Specific issues to be addressed include the incidence of linguistically-defined symptoms (e.g., agrammatism) within the classical syndromes (e.g., Broca's aphasia), and the extent to which the phenomenon of evolution of syndromes during recovery reflects substantive changes in language capacities. This third goal reflects an attempt to join the theories and methods developed in recent neurolinguistic studies of language impairment with the more traditional approach to the study of recovery from aphasia.

Communication in Aphasia and Other Organic Disorders

Edgar B. Zurif

Aphasia Research Center, Boston, MA 02130

Sponsor: National Institutes of Health

Purpose—The goal of the research is to investigate how communicative capacities are organized in the brain and to arrive at neurologically interpretable analyses of such capabilities. The hypothesis is that the effects of focal damage in the left and right hemispheres serves to disentangle cognitive systems that normally interact in the exercise of language-based communication.

The research encompasses three levels of communication: 1) a linguistically-specific embodied as the capacity to carry out syntactic analysis; 2) a lexical-semantic component based upon a lexical inventory and upon categories of extralinguistic knowledge that serve to structure word meanings; and, 3) a discourse component comprising the ca-

capacity to process meanings involved in stories, jokes, arguments, and other supra-sentential entities.

The specific investigations at the syntactic level will focus on thematic and surface structure contributions to sentence processing in aphasia. These studies make use of grammatical judgments and reaction time methodologies for the assessment of comprehension as it unfolds over time. Such "on-line" methods will also be used in the studies of lexical semantics; the foci at this second level will include denotative and connotative forms of knowledge in left hemisphere damaged aphasic and right hemisphere damaged patients.

Studies at the discourse level will examine the

effects of right brain damage, probing the nature of limitations in integrating textual material and in comprehending non-literal forms of language. This program should yield a fuller picture of communi-

cative capacity in aphasic and right hemisphere damaged patients, and provide a basis for implementing appropriate forms of language remediation.

Reorganization of Brain Function in Recovery from Aphasia

Andrew C. Papanicolaou, Ph.D.; Bartlett Moore, Ph.D.; Georg Deutsch, Ph.D.; Harry S. Levin, Ph.D.; Howard M. Eisenberg, M.D.

The University of Texas Medical Branch, Galveston, TX 77550

Sponsor: *The University of Texas Medical Branch; U.S. Department of Education*

Purpose—Most aphasic patients sustaining focal left hemisphere lesions recover at least partially their linguistic capabilities within about a year following injury or stroke. Among the mechanisms postulated to account for this phenomenon of spontaneous restitution of language is functional reorganization of the brain involving a hemispheric dominance shift or increasing involvement of the relatively intact right hemisphere in mediating language.

Progress—During the past year, we have explored this hypothesis using two physiological measures of hemispheric activation, evoked potentials (EPs) and regional cerebral blood flow (rCBF) along with a measure of shift in ear advantage using a dichotic listening procedure.

Preliminary Results—Consistent patterns of task-specific hemispheric activation have been obtained with the use of cortical EPs in the context of a probe paradigm. This consists of recording EPs to an irrelevant probe stimulus (a click or tone) from the left and right hemispheres during performance of various cognitive tasks. When the task is linguistic the amplitude of the probe EPs is attenuated more in the left hemisphere. This asymmetric attenuation is considered as an index of greater left hemisphere involvement in the language tasks. This pattern of greater left hemisphere involvement has been consistently obtained with normal subjects, and right hemisphere stroke patients. In contrast, the majority of the 22 left hemisphere stroke recovering aphasics we have examined thus far show the opposite pattern of greater right hemisphere engagement during verbal memory, shadowing, phonological, and semantic target detection tasks.

Similar indications of increased right hemisphere

participation in recovery from aphasia have been obtained from 11 of these patients using rCBF. This noninvasive procedure allows for indirect assessment of local metabolic rates (thus degree of activation) of various cortical regions. Unlike normal controls and right hemisphere stroke patients, the majority of recovering aphasics showed greater right temporal activation during a phonological target detection task. Moreover, 11 of the recovering aphasic patients were given a dichotic listening test which involves simultaneous presentation of a pair of different speech syllables to each ear and requires the subject to respond with the syllable they heard. Most normal subjects, as well as right hemisphere lesion patients, report most often the syllable presented in the right ear, thus showing a left hemisphere advantage for language. However, the majority of the recovered aphasics (eight of the 11) showed a left ear (therefore, right hemisphere) superiority.

Future Plans/Implications—Although the interpretation of the results obtained with each procedure cannot be considered definitive, the general concordance of the electrophysiologic, blood flow and dichotic listening data supports strongly the hypothesis that restitution of language following left hemisphere stroke is due to increasing involvement of the intact right hemisphere in many patients.

It is hoped that further investigation will elucidate the conditions and extent of this functional reorganization. Moreover, it is expected that the results of such investigations will be of value in designing appropriate language retraining strategies that would enhance the process of language rehabilitation among stroke victims.

Publications Resulting from This Research

- Habituation of Auditory Event-Related Potentials: A Comparison of Self-Initiated and Automated Stimulus Trains.** Bourbon WT, Will KW, Gary Jr. HE, Papanicolaou AC, *Electroencephalography and Clinical Neurophysiology*, 66:160-166, 1987.
- Memory Assessment in Neuropsychology.** Loring DW, Papanicolaou AC, *Journal of Clinical Experimental Neuropsychology*, 9:340-358, 1987.
- Electrophysiologic Methods for the Study of Attentional Deficits in Head Injury.** Papanicolaou AC, *Neurobehavioral Recovery from Head Injury*, Levin, HS, Eisenberg HM, Grafman J, (Eds.), New York: Oxford University Press, 1987.
- Convergent Evoked Potential and Cerebral Blood Flow Evidence of Task-Specific Hemispheric Differences.** Papanicolaou AC,

Deutsch G, Bourbon WT, Will KW, Eisenberg HM, *Electroencephalography and Clinical Neurophysiology*, 66:515-520, 1987.

Evoked Potential Correlates of Right Hemisphere Involvement in Language Recovery Following Stroke. Papanicolaou AC, Moore BD, Levin HS, Eisenberg HM, *Archives of Neurology*, 44:521-524, 1987.

Cerebral Blood Flow Evidence of Right Frontal Activation in Attention Demanding Tasks. Deutsch G, Papanicolaou AC, Bourbon WT, Eisenberg HM, *International Journal of Neuroscience* (in press).

Dichotic Listening Evidence of Right Hemisphere Involvement in Recovery from Aphasia Following Stroke. Moore BD, Papanicolaou AC, *Journal of Clinical and Experimental Neuropsychology* (in press).

C. Speech Impairment

3. Other

Effects of Real-Time Biofeedback on Dysarthric Speech

James A. Till, Ph.D., and Richard W. Light, M.D.
Veterans Administration Medical Center, Long Beach, CA 90822

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This research program is devoted to developing and testing the effectiveness of computer-controlled visual biofeedback in inducing changes in speech breathing and speech rate in normal and dysarthric subjects. Of particular interest are changes in speech intelligibility that may occur with changes in speech rate and speech breathing patterns. Cerebellar ataxic and Parkinson subjects are being studied and compared with normal control subjects.

Progress—The normative and procedural validation experiments have been completed. We have devel-

oped an algorithm which provides a real-time metric highly correlated with speech rate and are presently applying this technique to both normal and disordered subjects. Speech breathing patterns for both normal and disordered subjects have been identified. Our results thus far suggest that this technique can successfully induce changes in speech rate and speech breathing. The remainder of this grant period will be aimed at determining the effect of such changes on speech intelligibility and other related speech parameters.

Perceptual and Acoustical Characteristics of Tracheoesophageal Voice

Sarah E. Williams, Ph.D.; Tom Scanio, Ph.D.; Farid Karam, M.D.
Veterans Administration Medical Center, Bay Pines, FL 33504

Sponsor: VA Rehabilitation Research and Development Service (Pilot Proposal #C941-PA)

Purpose—Tracheoesophageal puncture is the newest procedure available for voice restoration of laryngectomy patients. It involves the use of a one-way

valve prosthesis inserted through a fistula in the posterior wall of the trachea into the esophagus. When air is expired from the lungs it may be diverted

into the esophagus by occlusion of the tracheostoma, and hence, produce vibration of the esophageal tissue resulting in voice. Only recently have attempts been made to study the characteristics of speech produced by patients following tracheoesophageal puncture. Our study attempts to fill voids which exist in current descriptions of tracheoesophageal speech.

The purpose of the present study is to examine perceptual and acoustical characteristics of tracheoesophageal speech. Different types of voice prostheses, as well as different methods of occluding the tracheostoma to divert air into the esophagus, will be used to determine if these factors influence perceptual and acoustical characteristics of tracheoesophageal speech. We hypothesize that speech characteristics will be influenced by systematic variation of these factors.

The projected goals are: 1) determine if speech

produced using various combinations of voice prostheses and methods of tracheostomal occlusion can be discriminated on the basis of specified perceptual and acoustical characteristics; and, 2) determine which combinations of voice prostheses and method of tracheostoma occlusion yields speech most similar to that of laryngeal speakers with normal voices on both perceptual and acoustical measures.

The results will indicate specific voice characteristics which may need attention in speech treatment following tracheoesophageal puncture. In addition, this investigation will provide information regarding which combination(s) of voice prostheses and method of stomal occlusion yields the most "normal" audible speech. It is hoped that this will assist tracheoesophageal puncture patients and speech pathologists in making a more informed decision regarding tracheoesophageal speech.

Transparent Access to Sources of Computer-Based Information

David L. Jaffe, M.S.E.

Rehabilitation Research and Development Center, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: VA Research and Development Core Funds; Digital Equipment Corporation

Purpose—A software program, KIOSK, has been developed that demonstrates how the barriers to obtaining computer-based information can be reduced, benefiting both able-bodied and disabled people.

Progress—The KIOSK software has been designed to run on both 8-bit and IBM-PC compatible computer systems. A DECtalk Speech Synthesizer completes the hardware system and provides a friendly interface between the computer and its data and individuals requesting information.

In operation, the user uses his/her home or business Touch-Tone telephone to dial the telephone number of the DECtalk Speech Synthesizer. The equipment answers the telephone and KIOSK then mediates the interaction between the caller and the computer. The software: 1) permits the DECtalk to speak computer-based text files; 2) receives data from the DECtalk on which Touch-Tone keys are pressed by the caller; and, 3) works with a knowledge of a structure for presenting the text files.

In the current implementation, the interaction

between the caller and the computer is accomplished through a series of computer-initiated speech output and caller responses. The user is presented with either instructions, information, or choices. The caller's response to a choice is made by pressing the Touch-Tone key corresponding to his/her selection. The DECtalk recognizes the keypress and causes the program branches in an appropriate manner based upon the response. This process is continued, with the computer sending information from text files to the DECtalk which are spoken over the telephone and the user making choices on how the interaction is to proceed.

For example, a typical choice might be: *Press 1* for information on recreational devices; *Press 2* for information on robotic applications; *Press 3* for information on new wheelchair developments.

KIOSK has been developed as a general-purpose program. It operates by structuring disk-based text files, presenting them verbally to the caller at the proper time, when the right sequence of choices has been made. The information provider designs this structure and provides the text files to be spoken

by the program. As such, KIOSK is a flexible Authoring System for the DECtalk Speech Synthesizer and can be used to disseminate a variety of information.

Preliminary Results—One current application being demonstrated at this facility is a voice-output version of this Center's 1986 Progress Reports, which are descriptions of the operation of this Center and its projects.

When called, the system welcomes the user and briefly describes its operation. The caller is first asked to press any Touch-Tone key to continue and subsequently asked to press the 0 key. After a short introduction to the Center, the user is asked to indicate in which of the three groups within the Center (Orthopaedic Biomechanics, Neuromuscular Systems, or Human-Machine Interface) he/she is interested. The user responds with a Touch-Tone keypress and the program branches to the information and projects of the chosen group. The title of a project is then presented and the caller is given the choice of whether to hear the text of the project, go on to the next project, or return to the previous menu of choices.

The KIOSK software has recently been used to create an information system serving blind athletes at their 1987 World Series of Beep Baseball at Ithaca College in Ithaca, New York. Competitors used their telephones to hear team scores and standings as well as information on how to get around campus and the immediate area. Listings of restaurants, shopping areas, bus schedules, and tourist sights were all included.

An unexplored application of KIOSK is the voice output dissemination of information that would normally be presented in traditional printed newsletter format or general consumer type information.

Future Plans/Implications—KIOSK makes it possi-

ble for individuals without access to or knowledge of computers to obtain computer-based information. Information requesters simply employ their Touch-Tone telephone, a device already in their home or business and one which they know how to use. The substantial barriers of having to buy and learn how to use a computer for obtaining computer-based information are eliminated. Visually-impaired people could benefit from this type of access, and it serves able-bodied individuals equally well. In addition, modem communication could be added to supply the same information to people who have computer systems, including hearing-impaired individuals. In summary, a system based on KIOSK serves persons who are disabled because of their lack of information and those that are disabled because they lack the funds and motivation to buy and learn how to use a computer to access sources of computer-based information.

The next extension of this work will allow a computer system to mediate the exchange of information between the caller and the information contained in a remote database such as CompuServe or computer-based bulletin board systems. This would be accomplished by first engaging in a dialog with the caller to determine the information required and then connecting to the appropriate information source. Next, the computer would send the required commands in the proper syntax to obtain the information from the remote system and present it to the user as synthesized speech. An electronic librarian would thus be created to transparently search multiple databases of electronic information for the caller.

Current Publications Resulting from This Research

Human-Machine Interfaces. Jaffe DL, *IEEE Short Course on Rehabilitation Engineering*, Palo Alto, CA, February, 1986.
Rehabilitation Applications of the DECtalk Speech Synthesizer. Jaffe DL, *Computer Technology for Disabled Conference*, Palo Alto, CA, March, 1986.

Neuropathophysiology of Speech Motor Impairments

James H. Abbs

University of Wisconsin, Madison, WI 53706

Sponsor: *National Institutes of Health*

Purpose—The overall goal of this clinical research center is to advance our understanding and treatment

of motor speech disorders. We are in the process of achieving this objective through an integrated

series of investigations involving perceptual, acoustic, aerodynamic, electromyographic, movement and force analyses, in many cases conducted simultaneously and/or on the same subjects for critical comparative interpretations. Specifically, our research program involves four major areas of concurrent activity: 1) intelligibility and acoustic and aerodynamic analyses of dysarthric speech; 2) de-

velopment of motor control impairment profiles for speech mechanism subsystems; 3) system physiology-based investigations directed at the neural substrates of speech motor function and dysfunction; and, 4) development, evaluation, and refinement of improved techniques for rehabilitation of motor speech disorders.

Structure and Acquisition of American Sign Language

Elissa L. Newport

University of Illinois, Department of Psychology, Champaign, IL 61820

Sponsor: National Institutes of Health

Purpose—This research will investigate the structure and acquisition of American Sign Language (ASL), a natural language of the deaf of North America. ASL may be acquired as a primary language either early or late in life, and either from native signers or from signers who themselves acquired the language late in life. Its study therefore provides an unusual opportunity to investigate the consequences of early versus late experience, and of wide variations in input environment, on the process by which a language is acquired and the ultimate character of its user's knowledge. Eight experiments are proposed, to test adult users of ASL as well as children who are in the process of acquiring ASL, with a test battery of ASL phonology, morphology, and syntax which we will devise.

Given our previous results, these experiments are expected to demonstrate: 1) that there are striking

differences in the knowledge of a language that users attain as a function of when they began to learn that language; and, 2) that there is striking uniformity in the knowledge of a language that users attain when they begin learning the language in infancy, despite wide variations in input environments. In addition, the experiments should reveal whether these phenomena are due to the nature of the acquisition process, to hitherto unnoticed details of the input, or to interference (or the lack of interference) from English.

The results should contribute to our understanding of the importance of early experience for language acquisition, and to the character of learning in childhood versus adulthood. In addition, they should contribute to decisions regarding language exposure, whether spoken or signed, in deaf education and parent counseling.

XVI. Miscellaneous

Report on Phase I and Phase II: An Epidemiological Assessment of Disabled Veterans in Guam, American Samoa, and Hawaii

Claude M. Chemtob, Ph.D., and D. William Wood, M.P.H., Ph.D.

VA Regional Office, Honolulu, HI 96850 and School of Public Health, University of Hawaii, Honolulu, HI 96822

Sponsor: VA Rehabilitation Research and Development Service

Purpose—VA medical services in the Hawaii, Guam, and American Samoa (HGS) region are currently very limited, and there is a lack of information on the size, characteristics, and health/medical care service needs of the disabled veterans of this area. This research project in three phases will address these informational needs and allow information-based planning and programming to be developed for this region.

Progress—In Phase I of this project, data related to the population characteristics of veterans in the HGS area were examined and gaps identified. Methodologies to collect these missing data were reviewed and recommendations made. In Phase II of the project, a sample of disabled veterans from Hawaii (N:225) were interviewed as a pretest of a survey instrument that was to be used in the larger population survey for Phase III.

Results—The review of the data related to the characteristics of the veteran population of Hawaii, Guam, and American Samoa revealed several important deficiencies. In particular, data on the ethnic diversity, and the mortality experience of Hawaii veterans were found to be inadequate. Data from Guam and American Samoa veterans were non-existent. Data related to health status, socioeconomic resources, and service utilization were seen as unreliable and often dated.

The results of the pilot study of disabled veterans on Oahu, while not representative, were useful in defining several areas for subsequent investigation. A positive association between VA-rated levels of disability and service utilization was found. Among higher rated disabled veterans, perceived needs for assistance were reported for a multitude of problems (unemployment, poor physical health, etc.).

Lower levels of patient satisfaction were specified in terms of inpatient care for service-connected disabilities, DOD outpatient care, and compensation for service-connected disabled veterans. The highest levels of patient satisfaction were expressed for dental services, outpatient clinic services, GI Bill, and VA home loans.

Accessibility to VA services emerged as another problem area. Poor communication between VA recipients and providers in areas such as benefits and service eligibility, and difficulties in getting to see the “right” person at VA for help with VA-related problems were the focus of the access problems.

Future Plans—Phases I and II have laid the groundwork for the community survey of disabled veterans that will commence shortly. The dimensions of that survey will include demographic and socioeconomic characteristics, disability information, accessibility and satisfaction questions, and general service utilization patterns.

A Pilot Study on the Efficacy of Injected Cross-Linked Collagen in the Treatment of Symptomatic Glottic Insufficiency

Charles N. Ford, M.D.

William S. Middleton Memorial Veterans Hospital, Madison, WI 53705

Sponsor: VA Rehabilitation Research and Development Service (Pilot Proposal #A900-PA)

Purpose—Glottic insufficiency is a significant health problem that commonly results from laryngeal nerve injury, conservation extirpative laryngeal surgery, laryngeal injury, neurologic disease, or aging. The most effective surgical treatment is injection of Teflon®, but this material evokes an intense foreign body reaction. Reported complications of Teflon® augmentation have largely been related to the properties of the material.

Collagen appears to be a safe bioimplant, which can be used for a broader range of glottic insufficiency problems. The properties of collagen that allow this include: low viscosity so that precise placement can be made through a fine bore needle, low reactivity permitting superficial implantation without extrusion, and collagen's tendency to soften

scar tissue, as in the post-surgical and post-traumatic larynx. The techniques to be explored in this study will entail collagen injection into histologically similar collagen-containing tissue planes in the larynx. The effect of such injections will be studied in a much more comprehensive manner than has been previously described for any augmentation substance in the larynx.

The overall objective is to demonstrate how injectable cross-linked collagen can facilitate and enhance the rehabilitation of patients who suffer from glottic insufficiency. Preliminary work with Zyderm® collagen implant injections showed good short-term results over a 12-month period; improved initial and long-term results with glutaraldehyde cross-linked collagen (GAX) is anticipated.

Augmentative Communication for Intensive Care Unit Patients

Lewis P. Goldstein, Ph.D., and Mary Blazey, RN, MSN, CCRN

Veterans Administration Medical Center, Gainesville, FL 32606

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Although there are many commercially available augmentative communication devices, there is no one communication program that meets the immediate needs of the intensive care unit patient. Available devices tend to be cumbersome in size, require considerable movement and effort, have a limited vocabulary and poor storage of information, are difficult to learn in a short period of time, and do not allow the patient to see the communicated message easily. The *Intensive Care Communicator*, developed by Kevin Neelands, was designed solely for patients in intensive care units and addresses all of the problems found in other programs.

The major objective of this project is to determine whether the Intensive Care Communicator program can effectively be employed as a means of communication between patients, staff, and family. Specific questions include the following: 1) Can acutely ill patients learn to use a single switch computer

program for communication? 2) Will patients be able to move to a five-switch computer program for communication within a limited short time period? 3) Can the patient's family and intensive care unit personnel interact with patients using an augmentive computer program for communication? and, 4) Are there significant differences on the communication satisfaction questionnaire between subjects using and subjects not using the computer program?

Progress—In order to meet safety regulations for the Intensive Care Unit, the computer system had to be connected to an isolation transformer. The equipment was also anchored securely to an overbedside table. Single switches and five switch controls were designed and fabricated. To develop word lists for the program, both intensive care patients and staff were interviewed to insure that appropriate words and categories would be included.

Preliminary Results—To date, only one patient has been selected for the program. The patient was a 45-year-old male with severe chronic obstructive pulmonary disease (COPD), tracheotomized and ventilator-dependent. He was unable to communicate except with head nodding and was reported to be extremely depressed. Orientation to the program for the patient and the patient's sister took approximately 20 minutes. He used the computer program daily for 16 days, at which time he was removed from the ventilator and was able to talk. During usage of the program he was reported to be less depressed and overall satisfaction of the program was rated high by the patient, the patient's sister,

and the staff.

Future Plans—Plans are to continue using the Intensive Care Communicator with as many patients as possible to determine that this program can be effectively used by all types of patients. No changes of the word lists or the program format will be made at this time so that comparisons between patients can be made. Future plans to develop more appropriate word lists, as well as additional features of the program (i.e., patient programming, larger print, stored message elimination, and development of the program for IBM computer compatibility) are anticipated.

Artificial Intelligence Strategies for Orthopedic Clinical Decision Making

J. Hizer, M.S.; R.L. Dooley, Ph.D.; E. Kimbrough, M.D.

Bioengineering Alliance of South Carolina; Clemson University, Clemson University, SC 29634; William Jennings Bryan Dorn Veterans Hospital, Columbia, SC 29203

Sponsor: VA Rehabilitation Research and Development Service; Bioengineering Alliance of South Carolina

Purpose—The domain chosen for this expert system was a differential diagnosis of osteoarthritis and rheumatoid arthritis. Interviews were conducted with an expert orthopedic surgeon in an attempt to extract as much knowledge of the field as possible. The desired knowledge was not that which could be found in textbooks, but rather the expertise gained by the surgeon through years of experience. It was this intangible experience which was sought in order to convert it into an expert system for the computer.

Progress—Through an iterative process of interviews and knowledge base development using an expert system shell, an expert system has been developed which suggests a differential diagnosis of types of arthritis.

Four areas of symptoms and clinical signs form a basis for the decision making process: presenting symptoms, physical examination findings, X-ray results, and laboratory results. To qualitatively test the expert system, ten case studies were compiled from medical records. These case studies, along

with attached questionnaires, were distributed to fifteen orthopedic surgeons. Each questionnaire requested a diagnosis of the associated case study, a percent certainty factor, and suggested treatment plan. These same case studies were used for consultations with the expert systems. In this manner, a comparison was made between the surgeon's opinions of the cases and the expert system's suggested diagnoses.

Preliminary Results—Of the ten cases studied, the results showed that in four of the cases the physician's diagnoses were in total agreement with the expert system. In four other cases, the responses agreed with the expert system after an in-depth study of the information. For one of the remaining cases, the results were undetermined. In only one of the cases was there disagreement between the physician's responses and the computer. The results indicated that an expert system is feasible in the orthopedic diagnosis domain. Expansion of the knowledge base could produce a system with great clinical efficacy.

Evaluation of One-Way Air Flow Valve Prostheses in Decannulation Procedures for Chronic Tracheotomized Patients

Richard W. Light, M.D., and James L. Aten, Ph.D.

Veterans Administration Medical Center, Long Beach, CA 90822

Sponsor: VA Rehabilitation Research and Development Service

Purpose—This research project has two main objectives. First, we wish to determine if a new technique for discontinuing the chronic tracheotomy results in a higher success rate and/or a shorter period of weaning. Second, we wish to determine if tests of pulmonary function can be used to predict which patients are likely to be weaned from their chronic tracheotomy. The project commenced in July 1987 and will continue for two years.

Progress—We propose to study 40 patients over a 2-year period with the following protocol: an initial evaluation will consist of maximal inspiratory and expiratory flow volume loops, with the tracheotomy open and occluded; measurements of maximal inspiratory and expiratory pressures; measurements of airway pressures and pleural pressures (using an

esophageal balloon) during tidal breathing; and measures of upper airway resistance on both inspiration and expiration. In addition, swallowing evaluations using videofluoroscopy and speech evaluations will be performed.

If the patient is found to be a suitable candidate for an attempt at decannulation, he will randomly be assigned to a standard treatment group or a treatment group using the Passy-Muir one-way valve. This valve allows inspiration through the tracheotomy but forces expiration through the larynx and mouth or nose. This allows the patient to speak and should facilitate mucociliary clearance. In each group the tracheotomy will be capped for progressively longer periods each day as tolerated by the patient. Patients in the valve group will have the valve in place when the airway is not occluded.

Psychiatric Rehabilitation in Nursing Homes

Margaret W. Linn, Ph.D.

Veterans Administration Medical Center, Miami, FL 33125

Sponsor: VA Rehabilitation Research and Development Service

Purpose—Nursing homes are now the largest single place of care for the mentally ill, yet nursing home staff have had little or no training in working with psychiatric patients. Existing studies show deterioration in behavior of mental patients after nursing home placement when compared with similar patients randomly assigned to VA nursing care units or continued psychiatric hospitalization. In the face of further financial constraints and an aging population of patients, it is likely that even more psychiatric patients will be sent to community nursing homes. Many of these patients have a potential for psychosocial and functional rehabilitation and, in others, behavioral deterioration could at least be forestalled. Training and consultation to staff in nursing homes offer the potential for improving psychiatric care. The objective of this research is to test the effects of training and a cost-effective

method of consultation for psychiatric rehabilitation in nursing homes.

Progress—Nine nursing homes were randomly assigned to either a training/consultation program designed to increase staff knowledge and attitudes about caring for the mentally ill or to a program with control conditions. Following the training, mental patients admitted to the homes will be studied regarding behavioral outcomes at 6 and 12 months, as well as whether treatment goals were attained. Half of the patients will be randomly assigned to have their treatment goals and attainments discussed with nursing home staff so the effects of individualized feedback to staff about patients can be evaluated. If this study shows that the training and feedback improve staff knowledge and attitudes as well as psychiatric patient outcomes, then the method

would be a cost-effective one for upgrading psychiatric services in nursing homes.

Preliminary Results/Future Plans—This project was funded in January, 1987. A training program was developed and pretested in the first three months of the study. In May, training of staff on each of three

shifts in six homes assigned to the six-week training program was initiated. Staff were pre- and post-tested on attitudes, knowledge, and skill in the three homes where training had been completed. The training will be completed by December, 1987, and patient intake will begin in January, 1988.

Assessment of the Swallow Reflex in Patients with Dysphagia

Adrienne L. Perlman, Ph.D.

Veterans Administration Medical Center, Iowa City, IA 52240

Sponsor: VA Rehabilitation Research and Development Service (Project #XC443-R)

Purpose—The purpose of this proposal is to develop a non-radiographic method by which investigators can study the swallow reflex with a variety of repeated measures designs. Although dynamic radiographic methods are the best means of assessing the competency of a swallow, repeated X-ray for assessment of improvement in swallowing may not be ethically justifiable nor conveniently arranged. This project is directed toward one aspect of swallowing, that of the swallow reflex. If the rest of the neuromuscular system functions well, but the reflex is not triggered, none of the protective movements of the larynx occur and the individual then becomes a prime candidate for the life-threatening problem of aspiration.

This study has three objectives. Objective I will confirm the use of the Laryngograph (EGG) and a high fidelity catheter pressure transducer as a valid and reliable method of measuring the time (T_s) between the completion of the oral phase of the swallow (T_1) and elevation of the larynx (T_2). Objective II will study healthy young adults and healthy elderly adults in order to identify possible age-dependent differences in T_1 - T_2 . Analysis of the effect of age on swallow (T_s) will be conducted by a four-way ANOVA using multiple observations per subject with three temperatures (cold, tepid, hot)

and two viscosities (liquid, paste). Tests for interaction and main effects will be performed.

Objective III will test the effectiveness of two current treatments in three subpopulations of patients with an absent or delayed swallow reflex. These patients will be taken from three general diagnostic groups; those with a swallow reflex disorder subsequent to: 1) surgery for oral/pharyngeal cancer; 2) CVA; and, 3) degenerative neuromuscular diseases and progressive dysphagia. Subjects will be randomly assigned to one of three treatment groups: 1) thermal stimulation (Logemann, 1983); 2) the Ramsey feeder (Ramsey, 1986); and, 3) no swallowing therapy.

A 2 x 2 x 3 contingency table will be prepared to evaluate the rate of improvement for T_1 - T_2 across treatment groups and diagnoses. A log linear model will evaluate whether there is a significant association between improved status and treatment that is independent of diagnosis. A two-way ANOVA for repeated measures on one factor will test for differences in subjects' responses to treatments. A profile analysis across the repeated measures will be used to describe the different treatment responses. The results of this investigation will provide important information for determining appropriate rehabilitation techniques for patients with dysphagia.

Dissemination of Rehabilitation Technologies

Alvin H. Sacks, Ph.D.; Robert A. Weisgerber, Ed.D.; Terry R. Armstrong, Ph.D.

American Institutes for Research, Palo Alto, CA 94302 and Rehabilitation Research and Development Service, Veterans Administration Medical Center, Palo Alto, CA 94304

Sponsor: *VA Rehabilitation Research and Development Service*

Purpose—Many of the technological innovations that rehabilitation researchers produce do not become available to the disabled because they are never manufactured and distributed commercially. We are studying the process of transferring new rehabilitation technologies from research prototypes to manufacturers. Our primary goal is to produce guidelines that will help rehabilitation technology researchers and administrators at the Palo Alto VA Rehabilitation Research and Development Center (RR&D Center) improve the likelihood that the products they develop that are intended for market will be manufactured and used. Our secondary goal is to inform policymakers in the VA about significant barriers to the successful transfer of technology that are created by current policies.

Progress—During the first phase of our 3-year project, we gathered information and created a framework for describing the process of transferring rehabilitation technology from the design stage to manufacturing. We reviewed the literature on technology transfer, gathered new information through interviews with selected members of the rehabilitation technology community, and visited selected technology development centers and manufacturing organizations. The preliminary framework we created describes a generalized process for the development and transfer of rehabilitation technologies. It focuses on the barriers to successful transfer that can arise and some possible strategies to overcome those barriers.

We are now surveying all projects at the RR&D Center and conducting interviews with selected researchers and engineers who have projects in different stages of development. We are giving special emphasis to projects in which computer

technology is being applied to the communication, manipulation, mobility, or recreation needs of people with disabilities. We will use the results of the survey and interviews to help identify questions about transfer that RR&D Center staff should be addressing at successive stages of the development of a technology. We will design strategies in the form of alternative decisions and actions that might be taken in response to these transfer questions.

Preliminary Results—Our preliminary findings indicate that the major barriers to successful transfer come from two sources: the lack of mechanisms for establishing relationships with manufacturers and confusion about rules and regulations for dealing with manufacturers while avoiding any conflict of interest.

Future Plans/Implications—We plan to test our strategies for overcoming barriers to transfer by trying them out with a small set of products being developed by the RR&D Center. We will choose products that are approaching critical transition points in the development and transfer process. We will then work with researchers and engineers as they use the strategies that are appropriate for the current status of the products. We will make any necessary revisions to the strategies and put them into a guidebook for the RR&D Center staff. We will structure the guidebook so that researchers can easily use it as a decision aid. We will also prepare an executive report that will inform policymakers in the VA about factors that seem to be impeding the transfer of technology. We will prepare a guidebook for researchers and a report for administrators during the final phase of the project.

Rehabilitation of Neurogenic Communication Disorders in Remote Settings

Robert T. Wertz, Ph.D.; Nina F. Dronkers, Ph.D.; Robert T. Knight, M.D.; Gregory K. Shenaut, Ph.D.; Jon L. Deal, Ph.D.

Veterans Administration Medical Center, Martinez, CA 94553

Sponsor: VA Rehabilitation Research and Development Service; Health Systems Research and Development

Purpose—This investigation is designed to test the efficacy of computer and video technology to provide appraisal and treatment for patients in remote settings who suffer neurogenic communication disorders. Currently, these patients either do not receive services, or they must travel long distances, or they must become inpatients for extended periods of time. We are simulating an existing treatment center's ability to provide appraisal and treatment in remote settings by closed circuit television and by computer-controlled video laserdisk over the telephone. Comparison of television and laserdisk delivery of services with traditional face-to-face appraisal and treatment will permit assessing the accuracy of appraisal and the efficacy of treatment in the television and laserdisk conditions.

Progress—Patients who suffer a neurogenic communication disorder—aphasia, apraxia of speech, dysarthria, dementia, etc.—are appraised by a different clinician in each of three conditions: traditional face-to-face, closed circuit television, and computer controlled video laserdisk over the telephone. A battery of standardized speech and language measures is administered in each condition. Thus, each patient receives a diagnosis by a different clinician in each condition. In addition, patients who are aphasic subsequent to a single left hemisphere thromboembolic infarct are randomly assigned to a 6-month treatment trial in one of the three conditions. Agreement in diagnosis and improvement during the treatment trial between face-to-face management and management by television or laserdisk will indicate the accuracy and efficacy of the latter two conditions for providing services to patients who reside in remote settings.

Preliminary Results—Over 400 patients have been screened for participation in the study. Sixty patients have met criteria for the appraisal study and 10 patients have met criteria for the treatment study. Results on the first block of 36 patients in the appraisal study show no significant differences in

diagnoses among the three conditions. Percent agreement among conditions ranged from 83 to 100 percent. A kappa analysis of diagnoses indicates all but one of 21 comparisons shows significant agreement ($p < .05$) among the three conditions. Comparison of performance on the two primary appraisal measures shows no significant differences in patient performance among conditions on either measure. Thus, the accuracy of patient performance and agreement in diagnosis in the television and laserdisk conditions is essentially the same as performance and diagnosis in traditional face-to-face management.

Performance by the first 10 patients entered in the aphasia treatment trial must be interpreted with caution, because the sample size in each condition is small, and randomization has yet to equate groups on a number of variables, for example, initial severity. Nevertheless, there is clinically significant improvement in all groups, 12 to 17 percentile units on the *Porch Index of Communicative Ability*, our primary outcome measure. And, there are no significant differences in improvement among groups. Thus, results to date indicate treatment by television or video laserdisk is as efficacious as treatment in traditional face-to-face management.

Future Plans/Implications—We continue to increase sample sizes in both the appraisal and treatment studies. If the initial results are replicated with larger samples, we will have demonstrated the accuracy and efficacy of two methods for providing services for patients who suffer neurogenic communication disorders and reside where services are not available. A proposal to field-test the equipment and methods developed in the simulation study has been submitted. Because the cost of delivering services in the two conditions differs markedly, \$200,000 for closed circuit television in one remote setting and \$15,000 for video laserdisk in one remote setting, field-testing will be confined to the latter.

Publications Resulting from This Research

Appraisal and Diagnosis of Neurogenic Communication Disorders in Remote Settings. Wertz RT, Dronkers NF, Bernstein-Ellis E, et al. In R.H. Brookshire (Ed.), *Clinical Aphasiology Conference Proceedings*, Vol. 17, BRK Publishers, Minneapolis, MN (in press).

Alternatives to Traditional Management of Aphasia: Trained Nonprofessionals and Technology. Wertz RT, invited presentation to the Clinical Update: Neurogenic Communica-

tion Disorders Conference, Tempe, AZ, October 10, 1986. **Alternative Methods for Managing Aphasia: Use of Nonprofessionals and Technology.** Wertz RT, invited presentation to the Conference, The Aphasic Adult: A Management Approach, Long Beach, CA, February 7, 1987.

Alternatives to Traditional Management of Aphasia. Wertz RT, invited presentation to St. Mary's Hospital, Paddington Health Authority, London, United Kingdom, March 16, 1987.

The Relationship Between Visual Perception and Social Perception in Cerebral Palsied Children

M. Quan-Hyatt, M.M.A.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: American Academy for Cerebral Palsy and Developmental Medicine

Purpose—The objective of this study is to examine the ability of cerebral palsied (CP) children to decode facial expressions; and to investigate the possible relationship between visual perceptual impairment and the ability to make accurate inferences about internal states from facial expressions. The relationship between performance on the recognition of facial expression task and measures of social and behavioral characteristics will also be explored.

The clinical goals of this study are twofold: 1) to determine whether clinical observations of decreased social maturity in CP children are related to their neurological impairment (as manifested by visual perceptual deficits); and, 2) to determine

whether training on specific aspects of social perception will improve performance.

Progress—Data will be collected in two sessions. In the first session, 40 cerebral palsied children, aged 9 to 12 years, with spasticity (hemiplegia and diplegia) and athetosis, will be compared with 30 normal children on measures of visual perception, recognition of facial expressions and social maturity. In the second session, both groups will be trained on a visual discrimination task, and asked to view the facial expression tapes for a second time. Multivariate statistics will be used to analyze the data.

Understanding Spasticity and the Effects of Rhizotomy Surgery

Christopher L. Vaughan, Ph.D.; Noel Eldridge, B.S.; Derek Wells, M.S.; Rebecca Copenhaver, B.S.
Rhodes Engineering Research Center, Clemson University, Clemson, SC 29634

Sponsor: Clemson University, College of Engineering

Purpose—This project was developed to study the effects of a neurosurgical procedure—selective posterior lumbar rhizotomy—on spasticity, particularly as applied to the cerebral palsy child.

Selective posterior lumbar rhizotomy (SPLR) is a procedure in which the afferent nerve roots of spastic patients are selectively divided in an effort to balance the facilitation and inhibition on the anterior horn cell. This project was initiated in Cape Town, South Africa, where we studied a series of 30 patients.

Progress—Our equipment consisted of a custom-designed digital camera system to study the patient's movement patterns immediately prior to surgery and between 6 and 12 months after surgery. We are now busy implementing this system with clinical colleagues at UCLA and the Rusk Institute in New York.

Preliminary Results—Our biomechanical studies on the patient's functional status before and after surgery would appear to provide strong evidence that

SPLR provides significant improvements for spastic cerebral palsy children. These data will be presented at two meetings in 1987—the International Society of Biomechanics Congress in Holland, and the American Academy of Cerebral Palsy meeting in Boston.

Future Plans/Implications—We are planning further and more basic studies in which an animal would be rendered spastic surgically. We would then use standard neurophysiological techniques (stimulation and EMG recording) to study the effects of SPLR.

We are presently building our own hardware environment in which the experiments would be executed and controlled from an IBM PC/AT. We will look at some of the fundamental aspects of SPLR and for this we will need to perform appropriate studies on animals.

The implications of this research are that it will provide new knowledge and a better understanding of SPLR, which has probably been one of the most significant developments in treating spastic cerebral palsy in the last decade.

Design and Validation of a Subject/Instrument Interface to Allow Collection of Selected Pulmonary Function and Selected Metabolic Measures of Children with Cerebral Palsy

B. McClenaghan, P.E.D. and R. Koheil, Dip.P. & O.T., B.Sc.(P.T.)
Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: Easter Seal Research Institute, Toronto, Canada; Variety Club of Ontario, Tent #28

Purpose—The purpose of this study was to design, construct and validate an instrument/subject interface to collect selected metabolic measures of children with cerebral palsy. Specifically, this instrument is intended for use with subjects who, because of their impairment, are unable to tolerate the traditional testing protocol (mouthpiece and noseclip).

Progress—Subjects for this study were solicited from a summer day camp program sponsored by Variety Village Sport Training and Fitness Centre. A total of 13 subjects ($n = 8$ impaired; $n = 5$ able-bodied) were used in the validation study. All testing was conducted during one session. Experimental procedures included an equipment orientation, and collection of resting and exercise metabolic data.

Values were collected at rest and during the performance of three exercise workloads for each of two experimental conditions, mouthpiece and the metabolic interface. Exercise was performed on a Siemens-Elema electrically-braked ergometer configured for arm pedaling. Metabolic values were obtained from a Beckman Metabolic Cart modified

to allow the collection of mouthpiece and low-flow metabolic interface values. Data of particular interest in this investigation included oxygen uptake ($V.O_2$) and carbon dioxide production (CO_2). Validation of the equipment was evaluated using a concurrent criterion procedure using the mouthpiece/noseclip as the criterion measure.

Results—Correlations at rest and across exercise levels for oxygen consumption and carbon dioxide production were found to be high (range .94 -.84) and statistically significant ($P < .05$). All correlations were also tested for reliability and found to be significantly reliable ($P < .05$). The metabolic interface, designed for this project, when used in a sealed, low-flow configuration appears to be a valid method to collect metabolic data on children at rest and during moderate levels of physical activity. All subjects tolerated the metabolic interface better than the mouthpiece and noseclip. These measures allow the clinically-based researcher to quantify the effects of selected rehabilitative techniques on the energy expenditure of the child.

Protective Headwear for Disabled Children

R. Moran, D.D.S., F.R.C.S.(C), and D. Bochmann, C.P.O.(C), F.C.B.C.
Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: The Hospital for Sick Children Foundation, Toronto, Canada

Purpose—The objective of this study is to provide effective head and facial protection for children with a high risk of injury due to falls. The project's specific goals are twofold: 1) to develop an inexpensive helmet with good fit, comfort, ventilation for coolness, adequate cosmesis and light weight; and, 2) to fit 10 children in a clinical trial and monitor the helmet's performance and durability.

Progress—The helmet that has been developed and tested consists of a hard outer shell and a softer inner liner. The outer shell, made of high-density polyethylene, is comprised of three parts: an anterior section, a posterior section and a chin cup. Corresponding liner parts, made of foamed polyethylene, fit into the shell, serving both to cushion the impact of falls and to interface the head shape with the shell.

During fitting, the orthotist adjusts each of the three parts of the helmet on the child's head. When the correct fit is achieved, the three parts are riveted together to maintain the custom fit. If necessary, further customizing is possible by trimming the edges or by the addition of liner inserts. Once donned, the

helmet is fastened in place using plastic clips which are part of the hinge mechanism. The snug fit prevents the fastened helmet from being removed. However, by releasing the plastic clips and operating the hinge, the rear part can pivot up with respect to the front, thus permitting the entire device to be removed from the head.

Results—The helmet's performance was evaluated clinically by ten people who wore it for 2 months. It was also tested for its impact properties in a biomechanical laboratory. Results showed that the helmet affords effective protection and was well received by both caregivers and wearers.

Future Plans/Implications—While this helmet provides the same protection as a custom-molded helmet, the cost is significantly reduced for several reasons. First, the parts are industrially produced in quantity, and secondly, the fitting procedure necessitates only one appointment with the orthotist. Only a medium-size helmet of this design was developed and tested. Two more sizes are necessary to fit the range of head sizes from 2 to 19 years old.

Monitoring Respiratory Patterns and Their Coordination with Swallowing in Cerebral Palsy

D. Kenny, D.D.S., Ph.D., and M. Milner, Ph.D., P.Eng., C.C.E.
Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: National Health Research and Development Programme, Health and Welfare Canada

Purpose—The aim of this project is to objectively monitor respiratory patterns in children with cerebral palsy and assess the coordination of swallowing and respiration.

The specific goals of the study are: 1) to further elucidate the nature of respiratory patterns and their function in children with cerebral palsy; 2) to refine and develop monitoring and calibration techniques based on inductance plethysmography for children with cerebral palsy; and 3) to collect and evaluate respiratory pattern data relative to airway control during swallowing.

Progress—Twelve subjects (Ss), aged 5 to 12 years, will participate in each of the three groups. Group I: non-neurologically impaired children; Group II: children with a primary diagnosis of spastic cerebral palsy; Group III: children with a primary diagnosis of athetoid cerebral palsy. The study consists of 4 one-hour sessions. Each session format is as follows: 1) quiet breathing, S at ease (not to exceed 5 minutes); 2) 3 minutes of monitored quiet breathing; 3) S asked to take as big a breath as possible and then relax; 4) repeat step 3 above; 5) one distinct sip of 5 ml. of water from a cup; 6) repeat step 5 above; 7)

continuous drinking of 75 ml. of water; 8) eating a bite-sized piece of cookie; 9) repeat step 8 above; 10) repeat step 7 above; and, 11) 3 minutes of monitored quiet breathing.

A respiratory inductance plethysmograph is utilized to monitor the respiratory patterns related to rib cage and abdominal synchrony. In addition, the EMG recordings of swallowing and mastication activity are monitored by the placement of surface electrodes over the infra-hyoid muscle group and masseter muscle.

Results—Statistically, the respiration rate of normal children is *less* than either of the two cerebral palsy groups. Normal tidal volume is *greater* than both cerebral palsy groups. Most importantly, the minute ventilation of the normal group was *greater* than both of the cerebral palsy groups.

Publication Resulting from This Research

Monitoring Respiration and Its Coordination with Swallowing in Cerebral Palsy by Means of Respiratory Inductance Plethysmography. Koheil R, Sochaniwskyj A, Bablich K, Ross D, *Developmental Medicine and Child Neurology* 28(S53):37, 1986.

Effects of Relaxed Breathing and Biofeedback on Bronchospasm in Chronic Asthma

H. Levison, M.D., F.R.C.S.(C), and M. Milner, Ph.D., P.Eng., C.C.E.
Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: *National Health Research and Development Programme, Health and Welfare Canada*

Purpose—This study was designed to assess the immediate effects of relaxed breathing and electromyographic (EMG) biofeedback upon pulmonary functioning after methacholine-induced bronchospasm.

The specific goals of the project were: 1) to objectively assess the immediate effects of relaxed breathing upon pulmonary functioning subsequent to bronchospasm induced by a methacholine challenge; 2) to assess whether EMG biofeedback potentiates relaxed breathing; and, 3) to explore the efficacy of frontalis and trapezius as feedback sources during EMG biofeedback training.

Progress—This study involved 22 subjects ranging in age from 6 to 18 years who were enrolled in the in-patient Family Asthma Rehabilitation Program (FARP) at the HMMC. A single-case study format A - B - AB - C - AC was the paradigm employed. All A phases are assessments of effects of non-use and use of self-regulatory strategies on pulmonary functions subsequent to methacholine challenge; B represents participation in FARP, including the learning of relaxed breathing; and C is the EMG biofeedback training using either the frontalis or trapezius muscle. Pulmonary function assessments

during A phases were carried out with an Eagle 1 spirometer and all EMG monitoring and biofeedback training was done using Autogen 1700 feedback electromyographs.

Results—Thirteen children passed through this protocol. Nine children underwent the assessment protocol only, without participating in the relaxed breathing and biofeedback phases. This was to assess the influence of medications on the stability of the asthma. It does not appear that the technique of relaxed breathing, either with or without EMG biofeedback augmentation has an effect upon recovery subsequent to methacholine-induced bronchospasm. However, it has been noted that the sensitivity to methacholine decreases over the course of the study for all children. Whether this result is due to drug changes or some psychological/physiological control of the bronchi is at this time unknown.

Publication Resulting from This Research

Evaluation of Relaxed Breathing and Its Augmentation with Biofeedback Upon Methacholine-Induced Bronchospasm in Paediatric Patients with Chronic Asthma. Levison H, Milner M, *Rehabilitation Digest* 17(2):13, 1986.

The Finance of Medical Rehabilitation Services: Interim Report on the Mary E. Switzer Distinguished Research Fellowship in Medical Rehabilitation Finance

Andrew I. Batavia, J.D., M.S.

National Rehabilitation Hospital, Washington, DC 20010

Sponsor: National Institute on Disability and Rehabilitation Research

Purpose—Pursuant to the Social Security Act Amendments of 1983, P.L. 98-21, Congress enacted Medicare's DRG-based Prospective Payment System (PPS), but exempted qualifying rehabilitation hospitals and units from payment under the Medicare PPS. In that legislation, Congress required that the Department of Health and Human Services report on the feasibility of developing a prospective payment system for medical rehabilitation. Since the enactment of P.L. 98-21, payors and providers of rehabilitation have been strongly interested in the options available for the payment of rehabilitative care.

NIDRR, the federal agency that funded this research fellowship, has indicated two priority objectives in the area of rehabilitation finance: 1) to develop payment models to achieve the most effective use of funds for medical rehabilitation services; and, 2) to identify and assess federal and state sources of payment for medical rehabilitation, and to describe the major private sector resources of payment and reimbursement. The purpose of this research fellowship is to address the various theoretical, empirical, and descriptive issues associated with NIDRR's priority objectives.

Progress—The two priority objectives of this research fellowship are addressed in two papers currently being developed, which are summarized as follows:

A. An Analysis of Models for the Payment of Rehabilitative Care. This paper, which addresses the theoretical (and to some extent, empirical) component of this research fellowship, has six sub-parts. They provide: 1) a background on medical rehabilitation and its finance; 2) a policy-oriented definition of the scope of medical rehabilitation; 3) criteria for evaluating medical rehabilitation payment policies; 4) an analysis of various payment models for medical rehabilitation; 5) an agenda for future research; and, 6) conclusions.

This paper considers all of the basic payment models (i.e., cost-based reimbursement, per diem or

per service-based prospective payment, DRG-based prospective payment, severity of illness-adjusted DRG prospective payment, per capita payment, and preferred provider arrangements) likely to be seriously considered for payment of medical rehabilitation services. Criteria for evaluating the probable effects of the various models on the provision of medical rehabilitation services are developed, weighed according to their relative importance to the rehabilitation industry, and applied systematically to the models.

It also examines the effects of the Medicare prospective payment system (and the PPS exemption for rehabilitation hospitals and units) on the provision of rehabilitative care. It reviews year-to-year hospital survey data furnished by the American Hospital Association (AHA) to determine the extent to which the increased supply of rehabilitation beds is part of a long-term trend or a specific response to Medicare's PPS exemption for medical rehabilitation hospitals and units. It also proposes an agenda for future research in the area of rehabilitation finance.

B. The Payors of Medical Rehabilitation. This series of two related papers describes all of the major payors of medical rehabilitation services and their payment policies. The first paper considers the rehabilitation payment policies of the *public sector* payors of medical rehabilitation: 1) Medicare; 2) Medicaid; 3) the Veterans Administration; and, 4) state vocational rehabilitation agencies. The second paper considers the *private sector* payors of medical rehabilitation: 1) private health insurance carriers (including Blue Cross/Blue Shield); 2) disability insurers; 3) casualty insurers; 4) workers' compensation plans; 5) health maintenance organizations; and, 6) self-insured employers.

Both papers in the series consider the eligibility, coverage, and payment policies of these payors for twelve rehabilitative services, and the extent to which the payors are meeting the rehabilitative needs of the disabled population. The papers attempt to address payment policies as they relate to all pro-

viders of medical rehabilitation services, not only the more intensive comprehensive medical rehabilitation programs.

Future Plans/Implications—The first paper, a theoretical treatment of rehabilitation payment models, will be published as a monograph by the American Hospital Association, Rehabilitation Hospitals and

Programs Section, later this year. The second paper, a descriptive treatment of the various payors of medical rehabilitation and their payment policies, will probably be published as a series of two articles in a rehabilitation-related journal shortly. The investigator presented these papers at the Annual American Hospital Association Conference at Los Angeles in November, 1987.

Information Dissemination in Communication, Control and Computer Access

Sara A. Brandenburg, M.A., C.C.C.; Peter A. Borden, B.A.; S. Ann Devine; Sandy L. Stern; Julie E. Gamradt, M.S.; Gregg C. Vanderheiden, Ph.D.

Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, Madison, WI 53705

Sponsor: *National Institute on Disability and Rehabilitation Research; University of Wisconsin-Madison; College-Hill Press, Div. of Little Brown and Company, Boston, MA*

Purpose—The activities and projects in this section of the Trace Center are aimed at disseminating current information about products, resources, and techniques available in the areas of communication, control and computer access, and identifying optimal methods for information dissemination in this field.

Progress—The Trace Center Reprint Service disseminates approximately 7,000 reprints per year. Forty-five different publications were listed this past year. Additionally, the Information and Referral Service continues to respond to approximately 1,200 requests received each year. Information is updated on a continual basis and includes information from the Trace product database, quick resource sheets, and sets of clinical application notes. A major project completed in the fall of 1986 was the production of the *Rehabilitation Resource Books on Communication, Control and Computer Access* (Volumes 1-3). These books replaced *The International Software/Hardware Registry, Second Edition*, and the *Nonvocal Communication Resource Book*, which were published in 1984 and 1985, respectively. *Resource Book 1—Communication Aids*; *Resource Book 2—Switches and Environmental Control*; and *Resource Book 3—Software and Hardware*, were published in January 1987 by College-Hill Press.

This comprehensive 1,000-page set includes over 900 entries with 500 photographs of hardware devices. Using desktop publishing techniques, the Trace Center was able to produce the most current resources available with a turnaround time of less than 2 months from compilation to distribution. This three-book series is extensively cross-referenced for logical and easy access. Using the series, consumers and professionals can quickly search for and identify assistive devices, software, and hardware for their needs.

Future Plans—As of the summer of 1987, a fourth volume to the Resource Book Series was being compiled. When completed, this volume will include approximately 300 new entries not available in Volumes 1-3. This fourth volume will be available from the Trace Center by the end of 1987. The Trace Center also is beginning to examine the needs for a computer-assisted information searching system for this area.

Publications Resulting from This Activity

Resource Book 1: Communication Aids; Resource Book 2: Switches and Environmental Controls; Resource Book 3: Software and Hardware. Brandenburg SA, Vanderheiden GC (Eds.), College-Hill Press, a division of Little Brown and Co., Inc., Boston, MA, 1987.

Industry-Based Employee Assistance Program

Joseph Demarsh, Ph.D.

Southwest Business and Industry Rehabilitation Association, Scottsdale, AZ 85251

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—The goal of SWBIRA's Industry-Based Employee Assistance Program Model is to determine possible solutions to problems of job retention encountered by developmentally disabled individuals once they are placed in an employment setting. It is hypothesized that the loss of employment by developmentally disabled persons is due to inadequate adjustment problems.

Progress—The structure of the project is quasi-experimental in design. Twenty individuals who 1) have a documented and confirmed diagnosis of developmental disability; 2) have access to transportation; 3) have previous vocational experience; 4) are at least eighteen years of age; 5) have documentation and can demonstrate specific skill training; and, 6) demonstrate a need for time-limited/on-going support services within an employment setting, have been selected and divided into three groups. Descriptions of the three groups are summarized below.

A) *The Treatment Group* has been placed in organizations with an existing Employee Assistance program. In addition to the services which the corporate Employee Assistance Program offers, this group is provided with intervention from the project staff. The set of interventions are adapted to a specialized Employee Assistance Program model for developmentally disabled employees.

B) *Control Group I* has been placed in corporations which have an existing Employee Assistance Program; however, this group will receive no additional intervention from the project staff. This group is being monitored periodically for data collection purposes.

C) *Control Group II* has been placed in corporations which do not presently have an established Employee Assistance Program. These individuals are being monitored but receive neither intervention from the project staff, nor the benefits of corporate Employee Assistance Program services.

Results—There are some factors that appear to be establishing trends in the project. The most obvious

factor deals with the job retention and the degree of support provided by the employer. It appears that without the support of a company that provides employee assistance or a specialized employee assistance program, developmentally disabled employees experience a high degree of failure in the employment setting. A comparative analysis of the three groups indicates that the participants in the treatment group and in Control Group I are coping and adapting to the work environment. They appear to be making the transition into the labor force and developing commitments. The termination of participants in these two groups has been extremely low. Five of the participants in the treatment group continue to be employed in their original job and two are unemployed at the present time. Of the two that are unemployed, one resigned her position and moved out of state. The other was working in a federally funded project which was discontinued. Her termination was not related to job performance, work adjustment, or work establishment. One hundred percent of the participants in Control Group I continue to be employed in their original positions. In contrast, the job retention of participants in Control Group II is minimal. Seventy-one percent are presently unemployed. One of these participants has held two positions in the past 6 months. Only 28 percent of the participants in control group II remain employed in their original positions.

Future Plans/Implications—This project intends to levy an impact directly on the developmentally disabled participant as well as focal groups in the community whose decisions and priorities determine the post employment resources available to developmentally disabled persons.

The impact on participants will be: increased annual earnings; increased job satisfaction and mobility; more available employment options; anticipated 80 percent retention rate at the end of 12 months. The impact on private and public sections will be: a reduction in chronic dependency on government programs; positive changes in family and community attitudes; decreases in retraining

and placement services.

Several manuals and publications will result from the Employer Assistance Program. An EAP manual comprised of 3 inservice training modules (one for the DD worker, one for the coworkers and super-

visors, and one for support persons) has been developed. Additionally, replication and outcome effectiveness information will be made available as the program progresses through its third year of operation.

Uses and Potential Uses of Information Technology by Rehabilitation Agencies

Laura A. Edwards, M.S.

Department of Graduate Studies in Visual Impairment, Pennsylvania College of Optometry, Philadelphia, PA 19141

Sponsor: National Institute on Disability and Rehabilitation Research (Fellowship Award)

Purpose—The fellowship focused on one overall goal: to produce a model for information technology selection and application to the decision-making and networking needs of rehabilitation service providers, administrators, educators, and researchers. Research activities involved state rehabilitation agency staff, directors of Regional Rehabilitation Continuing Education Programs, and directors of 5-year grants from the National Institute on Disability and Rehabilitation Research.

Four major objectives guided the research: 1) identify information technology uses; 2) determine the patterns, frequencies, and formats of information needed to facilitate performance; 3) develop a model to assess the cost effectiveness of these technologies; and, 4) propose new methods (a) to increase or refine the volume of useful information that can be exchanged among state agencies and between state agencies and information providers, such as NIDRR grantees; and, (b) by which automated programs can be used by the rehabilitation counselor to improve "hand-on" services.

Progress—A survey instrument provided data on the kinds of information kept and the kinds of technology used by the three research populations: agencies, RCEPS, and NIDRR research grantees. The survey identified the actual costs and budgeted costs (in ranges) for information technology. In addition, the instrument provided a checklist of perceived benefits and problems related to information technology systems used in the respondents' settings.

Visits to several state agencies produced case studies on system development and implementation in terms of potential cost effectiveness areas. Informal and formal interviews at several national con-

ferences contributed innovative ideas for automating counselor functions and for inter-/intra-organizational communications.

Survey responses were high. The results represent 89 percent of the state rehabilitation agencies, 77 percent of the NIDRR five-year grantees, and 73 percent of the 11 RCEPS. Survey findings include:

1) Costs of program-owned computer equipment is predominantly under \$15,000 for RCEPS, under \$100,000 for NIDRR five-year grantees, and under \$500,000 for state rehabilitation agencies.

2) The most popular hardware among the respondents are IBM microcomputers and compatibles and then Apple microcomputers and compatibles; among mainframes IBM leads with DEC & Honeywell trailing slightly behind.

3) The most popular commercially available software among the respondents are Lotus 1 2 3, D-Base, Word Perfect, Word Star, and SPSS.

4) Respondents state that all levels of staff use or are encouraged to use the computers. In 30 percent of the agencies clients have begun using the equipment.

5) More respondents perceived quicker access to stored information and greater capacity to process information for making more effective decisions than other benefits to computer systems.

6) None of the technical or nontechnical problems associated with computers generated more than a 49 percent response rate.

7) All respondents use telephone conference calls, state/national teleconferences, on-line national databases, and television broadcasts as needed. Of the agency respondents 81 percent use computer bulletin boards/networks daily or weekly. Thirty percent of the agencies use electronic mail daily and 15 percent as needed.

8) The degree of computerization by categories for agencies are: (1) client/caseload data (e.g., RSA R300/911, IWRPs, time/status), Range = 0-90 percent, Mean = 56 percent, Median = 60 percent, Mode = 60 percent; (2) services support data (e.g., authorizations, vendors, eval.) Range = 0-88 percent, Mean = 45 percent, Median = 50 percent, Mode = 50 percent; (3) personnel data (e.g., job descriptions, salary/fringes) Range = 0-100 percent, Mean = 39 percent, Median = 43 percent, Mode = 43 percent; (4) inservice training data (e.g., needs, workshop data, fiscal) Range = 0-67 percent, Mean = 19 percent, Median = 22 percent, Mode = 0; (5) program planning and evaluation data (e.g., audits, reviews) Range = 0-77 percent, Mean = 24 percent, Median = 22 percent, Mode = 11 percent; (6) other administrative data (e.g., manuals, inventories, lists) Range = 0-100 percent, Mean = 42 percent, Median = 38 percent, Mode = 11 percent.

9) The agencies having highest percentages of computerized items across all categories are (beginning with the highest) : *WI-C, *IL-C, *PA-G, *GA-C, *NY-G, MD-C, *AL-C, *NE-G, *AZ-C, *MN-G, *TX-G, OR-G, OK-C, SC-G, VA-G, RI-G, *WY-C, *CA-C. The states with asterisks have 60 percent or more in three to six categories. LA-C and NC-G

are high in three categories but not in percent of items computerized.

10) Among the research respondents 60 percent or more computerize statistical analyses, progress/final reports, articles, mailing lists, budget/income/expenses, salaries/fringe benefits.

11) Research respondents ranked information areas as follows: research data and analysis; potential funding sources requirements; literature reviews; needs surveys; impact of research results; potential subject sources and names; names of potential users of results; names of political/funding source contacts; sources of research support (e.g., advisory); names of experts for research design and content.

12) Fifty percent or more RCEP respondents computerize budget/income/expenses, mailing lists, training calendars, workshop descriptions and evaluation/statistical data.

Future Plans—A final report will present case studies, cost effectiveness models, and discussion of innovative techniques. Survey respondents will be receiving a resource guide to the selection and use of information technology for their participation in the research.

Disability Management and Rehabilitation: An Analysis of Programs, Costs and Outcomes

R.V. Habeck, Ph.D., C.R.C., and D.C. Munrowd, M.A., C.R.C.
Michigan State University, East Lansing, MI 48824

Sponsor: *National Institute on Disability and Rehabilitation Research*

Purpose—In 1984, Michigan State University was awarded a 3-year, field-initiated research grant by the National Institute on Disability and Rehabilitation Research to study the incidence, costs, and outcomes of rehabilitation and disability management among three major employers in Michigan. The purpose of the study was to investigate organizational culture, human resource policies, and specific benefit and intervention practices adopted by these employers to manage the incidence, costs, and outcomes of disability among their workforce.

Progress/Methodology—Three levels of analysis, including macroeconomic, organizational, and employee factors, were developed. Their interrelation-

ships provide an overall appreciation of the impact of the external environment on business operations as well as identifying potential barriers in each respective employer's management practices at the organizational and individual level.

At the macroeconomic level, a substudy of national and state economic and labor demographic data was developed to assess the impact of labor market economics, legislative initiatives, and health care trends and costs in Michigan. At the organizational level of each of the participating employers, information was derived from interviews with key personnel, data from questionnaires, on-site observations, reviews of company reports and data tracking systems, contractual agreements, and specific

program outcome data. Employee data were gathered in two companies through review of case files or surveys. A specific protocol was developed to capture demographic, medical and benefit costs, and employee outcome data for each individual. A policy initiative was studied by field interview in the third employer.

Results—Data analysis is currently being completed for two of the employers. A completed final report for the third employer is currently being reviewed by the company before release to the public. Specific reports with recommendations are in preparation for each employer along with a compilation of general findings that will summarize basic costs, outcomes, and factors affecting the disability management process.

The components of organizational cultures that elicit a positive response for human resource development, interventions that reduce costs, factors that distinguish effective disability management practices, and characteristics of employees at high risk for disability outcomes are summarized in the final reports and future publications of the project. Over the 3-year grant period, project staff have provided technical assistance to employers and rehabilitation providers.

Future Plans/Implications—It is anticipated that the results of the project will provide business, labor, government, health professionals, and disabled individuals with information useful in guiding the development of future programs. The culture of the organization has been determined in this study to play a significant role in employee investment in their work role and in contributing to the advent

and outcome of injury and chronic disability conditions among employees. Further research is needed to investigate the relationship among company policies, incidence of illness and injury, and the length of time an individual is away from the workforce to understand the specific linkages between the organization and its employees in relation to health and disability.

Publications Resulting from This Research

- Employer-based Disability Management and Rehabilitation Programs.** Galvin DE. In E.L. Pan, S.S. Newman, T.E. Backer and C.L. Vash (Eds.), *Annual Review of Rehabilitation* 5:173-215, Springer Publishing Company, New York, NY, 1986.
- Disability Management: A Comprehensive Framework for Prevention and Rehabilitation in the Workplace.** Tate DG, Habeck RV, Schwartz G, *Rehabilitation Literature* 47(9-10):230-235, 1986.
- Health Promotion, Disability Management, and Rehabilitation in the Workplace.** Galvin DE, *Rehabilitation Literature* 47(9-10):218-223, 1986.
- Disability Management and Rehabilitation in the Workplace.** Tate DG, Habeck RV (Eds.), *Journal of Applied Rehabilitation Counseling* (Special Issue), 17(3), 1986.
- Disability Management: Origins, Concepts, and Principles for Practice.** Tate DG, Habeck RV, Galvin DE, *Journal of Applied Rehabilitation Counseling* 17(3):5-12, 1986.
- Rehabilitation in an Industrial Setting.** Munrowd DC, Beecher PJ, *Journal of Applied Rehabilitation Counseling* 17(3):23-27, 1986.
- Disability Management Research: Current Status, Needs and Implications for Policy.** Galvin DE, Tate DE, Schwartz G, *Journal of Applied Rehabilitation Counseling* 17(3):43-48, 1986.
- Implications of Worksite Practice for Training and Educating Rehabilitation Counselors.** Habeck RV, Ellien V, *Journal of Applied Rehabilitation Counseling* 17(3):49-54, 1986.
- Overhauling Rehabilitation.** Tate DE, Munrowd DC, Habeck RV, *Business and Health* 4(9):32-35, 1987.
- Employer-based Rehabilitation Practice: An Educational Perspective.** Habeck RV, Munrowd DC, *Rehabilitation Education* 1(2), 1987.

Epidemiological Study of Pain

T.C. Chen

National Institute for Neurological and Communicative Disorders and Stroke, National Institutes of Health, Bethesda, MD

Sponsor: National Institutes of Health

Progress—The purpose of this project was to evaluate the overall and age-specific incidence rates of various chronic pain syndromes by developing a statistical technique to estimate incidence rates from age of onset data. The technique developed uses

available estimates of age of onset data for headache and approximates incidence rates by superimposing the age of onset rates onto the age distribution of the given population. The incidence rates of disabling and/or severe headache were evaluated with

data obtained from a Midwest nonclinical population survey.

Results—The validity of this procedure was evaluated by comparing the results with the incidence of

disabling headache estimated from the British Second National Study of Morbidity Statistics. A report on this work has been prepared and will be submitted for publication.

A Neurosensory Interdisciplinary Research Program: Tactile Stimulator Development

Kenneth O. Johnson

Johns Hopkins University, Baltimore, MD 21205

Sponsor: *National Institutes of Health*

Purpose—The broad objective is to focus the latest techniques of the physical sciences and modern technology on the solution of problems encountered in studies of the development, structure, function, and dysfunction of the nervous system, the neuromuscular system, and the communicative system. The School of Medicine and the Applied Physics Laboratory will collaborate to provide the stimulus, the expertise, and the environment to achieve this objective.

Progress—There are five specific research projects and one core project set forth. Two of the research projects are concerned with the design of instruments and apparatus to facilitate study of the electrical activity of neurons within the cortex of an awake, behaving monkey.

One is to develop multiple element microprobes which would allow simultaneous recording from several neurons. Only through simultaneous recordings can decisive data be obtained on functional connections between cortical cells. The other is to develop 2-dimensional isometric/torqueable manipulandums to facilitate the study of cortical neurons involved in the generation and spatial organization

of arm movements aimed at visual targets. This will permit testing two opposing hypotheses concerning the cortical control of movement.

The third project applies advanced signal processing techniques to detect and localize spatially epileptiform discharges through magnetoencephalographic measurements. The noninvasive spatial localization of epileptic foci is important investigationally and clinically.

In the fourth project, two distinct types of tactile stimulators will be developed: a closely-packed array of independently controllable elements for use in basic neurophysiological and psychophysical research, and a small, low power wearable device for use in human prosthetic systems. Suitable devices are currently unavailable.

In the fifth project, new instruments will be developed to improve the technical quality of microneurosurgical procedures with particular emphasis on neurosurgery. Microsurgery is of necessity a solo operation and there is need for technological assistance. The purpose of the Core Function is to facilitate the development and feasibility testing of new concepts for future neurosensory projects.

Development of a Data Management System for the Family Asthma Rehabilitation Program (FARP)

J. Hambley, Ph.D., and Y. Chua, M.D.

Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: *Private Donation to the Family Asthma Rehabilitation Program*

Purpose—The objectives of the project are two-fold: 1) to establish a data management system suitable for the management and evaluation of FARP activ-

ities; and 2) to examine the medical, psychological and demographic factors that influence the effectiveness of an in-patient asthma treatment program.

Progress—The project involves two phases. Phase One consisted of designing a database system for the program. Design activities included the review of current data collection methods and the development of computer-compatible inventories. The inventories encompass demographic information, medical indices, psychosocial adjustment levels of child and family, and the children's knowledge of asthma. Program computer resources were reviewed and upgraded for the establishment of a data entry and data maintenance system.

Phase Two of the project involves the implemen-

tation of the database system. The implementation activities include: 1) teaching staff to administer measures and manage data on the computer; 2) monitoring system activities to ensure fidelity of system design; and, 3) initiating descriptive and evaluative research.

Parallel to the implementation procedures, the project will develop appropriate fitness measures for the program. To date, phase one of the project is completed and present activities are focused on the implementation phase of the project.

An Innovative Approach to Continuing Health Care Education

Christopher L. Vaughan, Ph.D., and R. Larry Dooley, Ph.D.
Bioengineering Alliance of South Carolina, Clemson, SC 29634

Sponsor: RGK Foundation of Austin, TX; College of Engineering, Clemson University

Purpose—Technology has had a major impact on the delivery of health care in the past decade. Patients and clinicians alike are faced with a bewildering array of choices. Traditional education methods are simply inadequate to meet the challenges of the technological revolution. Our objectives are: 1) to set up an innovative teaching laboratory; 2) to integrate three exciting new technologies; and, 3) to specialize in the needs of patients with back pain, and the engineering skills required by orthopaedic surgeons.

Progress—Our system will be generally applicable to a wide range of students. We want to seek appropriate solutions to the problems of continuing health care education, so our system will adapt to the special needs of the individual student. We plan to implement a unique concept by combining three emerging technologies: artificial intelligence (e.g., the ability of a machine to understand human speech),

computer-aided instruction (already shown to motivate students and increase achievement), and the videodisc (instantaneous access to thousands of images). The Bioengineering Alliance of South Carolina is well-placed to succeed with this project: we have the people (engineers, scientists, and clinicians from the participating universities and hospitals), and we have the experience (demonstrated success for a related project with industrial and state support).

Future Plans/Implications—Within three years our laboratory will be self-sufficient: our educational courseware will be implemented not only in South Carolina, but elsewhere in the United States as well. We realize that the challenges that lie ahead are substantial, but we believe that our model, based on a human-centered approach, has great potential for success.

Assessing the Need for Management of the Neurogenic Bowel in the Pediatric Population

J. Hambley, Ph.D., and M. Taylor, R.N.
Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

Sponsor: Research Department, Hugh MacMillan Medical Centre

Purpose—The objective of this study is to develop a database identifying present management practices

and factors which might influence bowel management in a sample of spina bifida children.

Progress—This study involves 65 children ranging in age from 0 to 16 years old who attend the bi-monthly combined Spina Bifida Clinics and the monthly Teen Spina Bifida Clinic. The subjects were chosen randomly from the total sample and then grouped by age and sex. A computer-compatible questionnaire, consisting of 54 questions, was developed and individually administered by an experienced Registered Nurse/Research Assistant, through prescheduled parent/child/teen interviews.

Individual interviews were planned in order to gain a thorough understanding of: 1) early and present

bowel functioning; 2) methods of bowel management; 3) parental knowledge of factors affecting bowel functioning and management; 4) impact of bowel routine on child and family; 5) parents' assessment of need for a bowel management program; and, 6) urinary functioning and management.

The questionnaire data will be tabulated by computer, on a question by question basis, for all subjects grouped by age and sex. Descriptive statistics will be employed to analyze the data and comparisons between and across groups of subjects will be made.

Longitudinal Study of Public Expenditures for Services to the Handicapped

David Braddock, Ph.D.; Glenn Fujiura, Ph.D.; Richard Hemp, M.A.

Evaluation and Public Policy Analysis Program, Institute for the Study of Developmental Disabilities, The University of Illinois at Chicago, Chicago, IL 60608

Sponsor: *None Listed*

Purpose—The Evaluation and Public Policy Analysis Program conducts research on state and federal policies in mental retardation/developmental disabilities (MR/DD) services, and has developed extensive databases on state government expenditures for the decade from fiscal year (FY) 1977 through 1986. Also analyzed were federal government expenditure data spanning FY 1935 to 1985 for 82 separate programs. The third component of the study analyzed total (federal, state and local) MR/DD expenditures.

The study's methodology consisted of the collection of state budget documents from the Council of State Governments in Lexington, Kentucky, and in Washington, D.C., and from the Center for Research Libraries in Chicago. Documents were also obtained directly from the states, and extensive contacts with state officials augmented and confirmed data obtained from published sources. Comprehensive monographs (e.g., Braddock, Hemp, and Fujiura, 1986) were distributed to state and federal officials and to state advocacy organizations to encourage thorough review of analytical results prior to the publication of journal articles.

Results—A major finding of the study over-all was the extensive Federal Medicaid support from the Intermediate Care Facility for the Mentally Retarded (ICF/MR) program devoted to large congregate in-

stitutions (87 percent of Federal ICF/MR dollars in FY 1986). This finding has significant implications in Congressional discussions of Medicaid Reform (the Community and Family Living Amendments). The State Government analysis also documented the continuing steady decline in average daily population of public MR/DD institutions, a recent increase in federal ICF/MR support for small, community-based services, and a declining level of federal support for community services from the Title XX/Social Services Block Grant.

The Federal Government analysis noted that since the 1950's MR/DD spending as a share of the total Federal budget has grown rapidly, consisting primarily of income maintenance (Supplemental Security Income and Adult Disabled Child payments) and services programs (ICF/MR, special education and vocational rehabilitation). However, Federal support of training and of research for MR/DD has declined rapidly in real dollar terms since the early 1970's. The third study component indicated that nearly \$17 billion in federal, state, and local funds were deployed for MR/DD services in FY 1984.

Honors in 1987—The Longitudinal Study received two singular honors in 1987: Dr. David Braddock was the recipient of the Distinguished Research Award, the most prestigious offered by the Association for Retarded Citizens of the U.S. The Na-

tional Study article (Braddock, Hemp, and Fujiura, 1987) was selected as the feature article in the September issue of the *American Journal of Mental Deficiency*, with commentary from Elizabeth Boggs, Laird Heal, H. Rutherford Turnbull, III, Sen. Lowell

Weicker, and Wolf Wofensberger.

The Institute for the Study of Developmental Disabilities offers a list of publications in journals and books, related to this research.

Section II.

Sponsor Program Summaries with Index to Progress Reports

VA Rehabilitation Research and Development Service
810 Vermont Avenue, N.W.
Washington, D.C. 20420
Margaret J. Giannini, Director

The mission of the Rehabilitation Research and Development Service (RRDS) program is to improve the quality of life of disabled veterans by making them more functionally independent. This mission is advanced through ongoing research projects in such priority areas as prosthetics/amputation, spinal cord injury, and sensory aids. Areas of special emphasis include aging, physical fitness, and psychosocial rehabilitation (e.g., dementia, schizophrenia, Alzheimer's disease, etc.).

During FY 1987, 142 Rehabilitation R&D projects, including interagency agreements, pilot projects, and special projects were conducted at over 58 VA Medical Centers, including the two Rehabilitation Research and Development Centers at Hines, IL and Palo Alto, CA and the newly-established Atlanta Rehab R&D Unit, in Decatur, GA.

In the areas of prosthetics, amputation, and orthotics, VA sponsored researchers are testing new materials and using computer technology such as CAD/CAM to develop a new generation of artificial limbs. For spinal cord injuries, the use of robotics continues to be studied, as does the possibility that computer-controlled electrical stimulation can be used to restore function to paralyzed limbs. Research projects in the area of sensory aids include the development of advanced mobility aids for the visually impaired, digital hearing aids for the hearing impaired, and a multi-hospital study in which machine-assisted therapy is provided via telephone to stroke patients who are aphasic.

The VA Rehabilitation Research and Development Service sponsors a national program to review proposals submitted by researchers in the rehabilitation field. The Scientific Review and Evaluation Board for Rehabilitation Research and Development and Ad Hoc members assess proposals for their scientific/technical merit, budgetary needs, and time requirements. In 1987, the Board approved 88 proposals for research projects in the three general priority areas. In addition, 13 pilot projects were approved to run for 1 year. Pilot projects are designed

to test the feasibility of developing data, a technique, or a procedure prior to undertaking a regular research study.

INNOVATION IN TECHNOLOGY TRANSFER

MOTEC (Mobile Technology Center for the Physically Challenged)

MOTEC INDEPENDENCE '87, A National Rehabilitation Technology Convocation and Exposition for Disabled American Veterans, was held in March 1987 in Washington, D.C.

The VA Rehabilitation R&D Service's MOTEC brings rehabilitation engineering information to veteran consumers in their homes and market areas. MOTEC uses tractor-trailers to carry the Technology Center exhibit to the consumer throughout the country. MOTEC makes it possible for disabled veterans to gain direct "hands on" access to the latest rehabilitation devices.

MOTEC will serve as a vital component in an expanding Veterans Administration/Department of Commerce initiative to put the latest technological advances into the hands of the disabled veteran and other consumers.

REHABILITATION RESEARCH AND DEVELOPMENT SERVICE WORKSHOPS

Workshops conducted by RRDS serve two major functions. One is to review and evaluate projects ongoing at particular centers, in particular subject areas, or, in general, all projects sponsored by RRDS. Another purpose of workshops is to identify new need areas for research and set priorities for the development of projects. Following are brief descriptions of some recent RRDS-sponsored workshops.

Low Vision and the Elderly Workshop

In June 1986, RRDS identified the need to increase the focus of research on low vision as it relates to an aging veteran population. An Interagency Agreement was made with The National Institute on Aging and the National Aeronautics and Space Agency to encourage and jointly sponsor research and development projects in five priority areas: reading aids; assistance in near tasks other than reading; visual discrimination

under low illumination; visual requirements for spatial orientation; and assessment of visual performance.

Schizophrenia Workshop

As a result of this workshop, held in October 1986, RRDS has encouraged research to develop ways to improve the clinical management and rehabilitation of veterans with schizophrenia.

The specific goals of rehabilitation research for patients with schizophrenia are: a) to place patients in environments that enhance and sustain their ability to function, whether it be in a hospital or in another type of community-based facility; b) to develop and assess rehabilitation strategies based on solid scientific understanding of schizophrenic illness; and, c) to identify characteristics of patients that will predict success with particular interventions.

Three groups of schizophrenic patients are of special interest in meeting these goals: 1) elderly patients in whom rehabilitation efforts may be complicated by the presence of other disorders that develop with age; 2) patients who have been termed chronic, i.e., persons whose disorder is characterized by frequent returns to the hospital and by marginal adjustment in the community between hospitalization; and, 3) patients who have a limited response to standard antipsychotic medication.

Dementia Workshop

A workshop was held in October 1986 to identify priority areas for research and development activities that will impact on the rehabilitation of veterans with dementia. The following objectives were set: improve functional autonomy; increase comfort and safety; reduce the need for crisis-intervention by caregivers and negative interactions between caregivers and patients; increase the predictability of behavioral changes associated with dementia; and, reduce the stress and time-demands placed on caregivers of patients with dementia.

Audiology Workshop

VA researchers from around the nation met in November 1986 to review existing R&D priorities and set new ones. The revised priorities focused on clinical management and rehabilitation of the hearing-impaired veteran.

The following areas were cited for research and development consideration: the elderly and other specific populations; communicative rehabilitation; electrophysiologic measures; hearing aids and implantable devices; prospects for prevention and early detection of hearing loss; psychoacoustics, speech perception, and signal processing; tinnitus; and, vestibular dysfunction.

Speech Pathology Workshop

VA speech pathologists convened in a parallel meeting to the audiologists in November 1986, to review their existing R&D priorities. Areas for rehabilitation research and development consideration were: new devices and materials to be used in speech therapy; development of improved diagnostic measurement; rehabilitative outcome studies; communication assessment; and, new methods for prevention and early detection of speech-related problems.

INTERAGENCY AGREEMENTS FY 1987

UNISTIK Hand Controller

An interagency agreement was negotiated between the VA and NASA in 1981 for the development of a vehicle hand controller based on the design of the NASA Lunar Rover. NASA assumed responsibility for management and evaluation of the engineering development, while the VA, through RRDS, developed protocols for, and carried out, the clinical testing and evaluation.

The result of this effort is the UNISTIK hand control system, which allows severely disabled individuals to control with one hand the primary driving functions (steering, acceleration, and braking) of a conventional vehicle. The system has proven to be simple to operate, low in cost, and easy to install on conventional vehicles.

A meeting sponsored by RRDS was held in June 1987 to stimulate the manufacture of the UNISTIK system. As a result, several van manufacturing/conversion/sales companies have negotiated for licenses to produce and distribute the system.

Functional Electrical Stimulation (FES)

Different FES systems produce different stimulation parameters, and thus similar stimulation sequences often produce significantly different results. A need was identified for a uniform stimulation system so that research results can be parametrically compared.

This need has resulted in a cooperative effort among Case Western Reserve University, VA RRDS, and NASA. A prototype 8-channel stimulator has been developed by researchers at Case Western. VA RRDS will make the stimulator available to researchers who will provide data to RRDS for parametric analysis. The manufacture of the stimulator will be managed by NASA.

Automated Manufacture of Mobility Aids Using CAD/CAM

This is an Interagency Agreement between the VA and NASA for the design and automated manufacture of a CAD/CAM prototype system.

Previously, both agencies had been involved in the technological development of CAD/CAM. The VA combined its effort with researchers in England, where CAD/CAM was employed in the development of an automated carving and forming system for making prostheses for below-knee amputees. An RRDS-conducted workshop brought Dr. Ron Davies, the project manager for the English automated prostheses project, together with VA researchers who expressed interest in becoming involved in this work.

The Seattle Prosthetic Research Study (PRS), directed by Dr. Ernest Burgess, conducted an across the ocean experiment in which amputee stump measurements taken in the United States were transmitted to England, where the automatic rectification and manufacture of the limbs occurred. These limbs were then returned to the Seattle PRS for fitting. The results obtained on more than 20 patients fitted to date are of equal quality, and are much quicker to produce than those obtained by traditional practice.

VA RRDS is now working with Seattle Prosthetics Research Study, directed by Ernest Burgess, M.D.; Northwestern Uni-

versity Prosthetics Research Laboratory, directed by Dudley Childress, Ph.D.; and New York University, Rusk Institute, directed by Richard Lehneis, Ph.D., in the development of a national plan. Under this plan, it is proposed that equipment be purchased from England, and that evaluation of this technology be expanded nationally to approximately 200 below-knee amputees.

The Interagency Agreement with NASA was expanded to include work by NASA Langley with Research Triangle Institute, the University of North Carolina, and North Carolina State University for the development of algorithms, edge-detection techniques, and methods for handling the large amount of data anticipated from the non-contact foot measurement system. A prototype device is expected to be ready for evaluation within 2 years.

Integrated System for the Management of Wandering Behavior in the Memory-Impaired Elderly

This is a five-agency agreement between the VA RRDS, The Administration on Aging, the National Aeronautics and Space Administration, the National Institute on Aging, and the National Institute on Disability and Rehabilitation Research.

The purpose of this effort is to develop a notification and locator system to aid caregivers in the management of wandering behavior as exhibited by the clinically diagnosed mild to moderately cognitively-impaired elderly. This includes those persons suffering from dementia of the Alzheimer's type as well as other dementias.

VA and the Department of Commerce

The VA RRDS and the Department of Commerce have joined together to stimulate private sector businesses in marketing devices for the disabled that have resulted from VA RRDS-sponsored research and development. A special focus will be on involvement of minority-owned businesses.

The following are reports on the year's activities at the two R&D Centers and the R&D Unit, listings of projects conducted at VA Centers, through Interagency Agreements, and, finally, through funding from VA facilities other than RRDS.

Rehabilitation Research and Development Center Veterans Administration Hines Hospital Hines, IL 60141

John Trimble, Ph.D., Director

In Fiscal Year 1987, the center continued to focus its efforts in the areas of blind rehabilitation, low vision

research, musculoskeletal rehabilitation, and spinal cord injury. The Blind Rehabilitation Research Program made significant progress in research on how blind persons perceive spatial layouts and in research on physical correlates of the subjective attributes of tactually perceived symbols. The Low Vision Research Program continued the study of the relationship between measures of visual function and the performance of perceptual tasks, in developing new optical aids, in studying the way visually-impaired persons use low vision aids, and in developing new techniques for enhancing the quality of images. The Musculoskeletal Rehabilitation Research Program has developed advanced techniques for studying human locomotion and has made significant progress in studies on the effects of various treatments for degenerative disc disease. The Spinal Cord Injury Research Program has advanced its work on electrical stimulation and wheelchair exercise. Our research on the use of electrical stimulation for muscle restrengthening has provided valuable data that may soon have important clinical uses. Studies on the uses of electrical stimulation for bladder control have also been productive. Their results may soon be tested clinically. Our study on the benefits of wheelchair exercise have provided valuable data and produced a new exerciser that has attracted the attention of several manufacturers.

Throughout the year, we also have continued our special emphasis on commercializing technology by working directly with manufacturers and local and state agencies for technology transfer. The center hosted a conference on "Minority and Small Business Opportunities in Rehabilitation Technology" in collaboration with the Minority Business Development Agency, the Small Business Administration, and the University of Illinois at Chicago. The conference was attended by 90 people representing 10 states and the center is now actively working with several of the attendees. A Technology Transfer Specialist has been appointed to ensure that the initiatives created by the conference continue in the future.

	Page
Factors Influencing Joint Compliance and Reflex Mechanisms in Spinal Cord Injury	84
Sacral Nerve Stimulation for Neurogenic Bladder Management in Spinal Dog	106
Electric Field Distribution in the Injured Spinal Cord	117
Interactive Videodisk Training for Self-Care Skills.	129
Interactive Videodisk Training for Self-Care Skills (Project Extension).	130
Wheelchair Graded Exercise Test for Patients with Lower Limb Disabilities	139
Muscle Re-education in Incomplete Quadriplegia by Electrical Stimulation	210
Electrical Stimulation of Paralyzed Muscle After Spinal Injury	212
Pupillary Function in Elderly Individuals with Impaired Night Driving Vision	363
Predicting the Visual Abilities of Partially Sighted Persons	364

Measuring the Mobility of Blind Travelers 390

Measuring the Spatial Layout Knowledge of Visually Impaired Adults 391

Rehabilitation Research and Development Center
Veterans Administration Medical Center
Palo Alto, CA 94304

Larry J. Leifer, Ph.D., Director

The Palo Alto Rehabilitation R&D Center has renewed its commitment to bringing the finest engineering in medical science technology to veterans with physical and cognitive disabilities. It is the intent of our labor that new knowledge about disabilities, new methods of treating dysfunction and new assistive devices will lead to independent and productive lives where this would not otherwise be possible. Achievement of this objective is facilitated by affiliation with the Stanford University School of Engineering and Medicine. Collaborative associations with NASA Ames Research Center, Massachusetts Institute of Technology, University of Maryland, University of Santa Clara, University of California at Berkeley, University of California at Los Angeles, McGill University, Vanderbilt University, Delft University (Netherlands), Children's Hospital at Stanford, Santa Clara Valley Medical Center, American Foundation for the Blind, Smith-Kettlewell Eye Foundation, and the Paralyzed Veterans of America are all important to our mission.

The Orthopedic Biomechanics Program has made considerable progress with the development of a unified model for the relationship between medical and strain energy and the growth, development, and eventual reabsorption of bone and cartilage. This unified theory has important implications for the design of joint replacement orthoses and for fracture healing. The Neuromuscular Systems Program has developed a comprehensive approach to the analytic modeling of nerves, muscle, and skeletal mechanics. In combinations with electrophysiological and kinesiological experiments, these studies lead towards optimal strategies for restoration of standing and walking through functional electrical stimulation. The Human-Machine Integration Program has completed several lines of device development and is now engaged in a strategic shift towards integration of artificial intelligence technology and manipulation, navigative and communication aids (cognitive orthoses). Work on powered mobility has come to a close with the commercial availability of a "smart" omni-directional wheelchair. Development of a bicycle for manual wheelchair users has also been completed. The design is in limited production and entering formal evaluation studies. A third generation Desktop Vocational Assistant Robot is ready for vocational field studies and limited production.

We are pleased that several devices reported in previous years have survived the arduous path from concept to production reality. New federal laws and renewed emphasis on a structured approach to technology transfer

have helped to make this a particularly productive year, and one that included our first "Manufacturers Workshop."

	Page
DataGlove Semi-Automated Hand Function Evaluation System	56
Design Stress Analysis of Porous Ingrowth Hip Replacements	71
Design Concepts for a Porous-Ingrowth, Prosthetic Tibial Component	78
A Pilot Project on Skin Blood Flow Response to Loading.	85
A Pilot Study on Alterations in Blood Rheology in Spinal Cord Injured Patients	105
Treatment of Physiological Impotence	128
Handbike, an Arm-Powered Bicycle (with the Telephone Pioneers of America; British Columbia Program for the International Year of the Disabled Person, through the Univ. of British Columbia Athletic Dept.; Stanford Mechanical Engineering Design Division; and, Stanford Center for Design Research).	155
An Instructable Robotic Aid: A Pilot Proposal.	171
Application of a Robotic Aid for the Severely Physically Disabled	173
Evaluation of a Desk-Top Robotic Aid with High-Level Quadriplegics	173
Design of a Desk-Top Environment for a Robotic Aid for the Severely Disabled.	174
Development of a Mobile Robotic Aid for the Severely Disabled	175
Computer Models for Designing Functional Electrical Stimulation Systems for Paraplegic Standing and Walking.	234
Development of a Life Satisfaction Scale Applicable for People with Severe Disabilities (with the National Institute on Disability and Rehabilitation Research)	238
Optimal Biomechanical Design/Development of Arm-Powered Mobility Devices	278
Stress Analysis of Internal Fracture Fixation of Long Bones	283
Decomposition Analysis of the Surface Electromyogram.	295
Automatic Decomposition of the Electromyogram	296
Electrophysiological Studies on Nerve Repair and Regeneration.	309
Nerve Coupler: Sutureless Peripheral Nerve Repair at the Fascicular Level.	310
Establishing Design/Operational Features for Portable Blind Reading Aids	392
Computer-Aided Visual Communication for Severely Impaired Aphasics	429
Dissemination of Rehabilitation Technologies.	445

Atlanta Rehabilitation Research and Development Unit
Veterans Administration Medical Center
Decatur, GA 30033

Franklyn K. Coombs, Director

The Rehabilitation R&D Unit has accepted the challenge of "Aging and Rehabilitation" as its pri-

mary focus. The debilitating conditions that accompany aging in some individuals are an increasing healthcare problem for the VA. It is projected that the VA population of veterans over 65 years of age will double by 1990 and double again by the year 2000. This group represents the fastest growing segment of the veteran population, and consumes more than 65 percent of the healthcare resources of the VA system. This unit is concentrating on the rehabilitation aspects of aging, rather than the biological aspects of aging. We are engaged in studies concerning increased independence, wellness, mobility, and quality of life of elderly people, whether they live at home, by themselves or with other family members, or are in institutions.

The unit conducted ten merit approved projects during FY 1987, two of which had extramural support. Five papers were published and 13 abstracts or poster sessions were presented during this reporting period. The unit staff also conducted the following ten pilot studies with core funds that lead to the development of merit proposals:

Spatial Orientation in Aging. A study of the effects of aging on spatial cognition and orientation. One special area of interest is why elderly people apparently become more easily disoriented or "lost" than younger people.

Epidemiological Study of Falls Among the Elderly. A study of the causes of falls by elderly people. The two special areas of interest are where people fall and what environmental factors contribute to the occurrence of falls.

Visual Assessment in Aging. A study of changes in clinical visual measures, such as contrast sensitivity and dark focus of accommodation, as they relate to distance and depth perception in the elderly.

Automated Visual Acuity and Perimetry. A study of improved clinical visual testing techniques to provide for easier and more reliable testing of vision, particularly for rapid screening of vision.

Image Enhancement of Closed Circuit Television (CCTV). A study of computer-assisted techniques to improve the contrast sensitivity, edge definition, and character identification of print images on CCTV's.

Exercise Devices for the Elderly or Disabled. A study of modified exercise equipment for use by the elderly or disabled, with a focus on health enhancement and wellness.

Automated EEG Analysis. A study of computer techniques, including expert systems and artificial

intelligence schemes, to decipher EEG patterns or evoked potentials. The focus is on the effect of medication interaction in patients with suspected dementia, particularly of the Alzheimer's type.

Syme Ankle Prosthesis. The design of a new ankle prosthesis for Syme amputees that has the same rotational characteristics as a natural ankle, and is less than one and one-half inches in height.

Hip Abductor Force Measurement. The design of a test stand and force transducer to measure the force generated by the hip abductor muscles, for use in rehabilitation therapy following hip replacement surgery.

Simplified Gait Analysis. The design of a simplified gait analysis method based on a three-axis accelerometer system. The concept is to integrate the acceleration data over time to obtain velocity data, which will provide useful information on pathological gait.[xm[cm

	Page
Design of a New Toilet: Transfer and Access Pilot Study	154
Design of Showers and Bathing Fixtures for Disabled and Elderly Veterans.	154
Electrical Stimulation of Osteogenesis Using Selected Techniques	229
Blood Velocity and Spectra Estimations from Doppler Ultrasound	327
The Use of the Electroretinogram to Predict Retinal Cell Activity.	363
Evaluation of Electronic Travel Aids (ETAs) for Visually-Impaired Individuals.	389
The Human Factors Design of a Large Print Display.	395
Rabbit ERG Responses to White-Noise Modulated Stimuli	403

The following VA Medical Centers and other institutions have reported projects sponsored fully or in part by the Rehabilitation Research and Development Service.

(Note: VA Centers are listed alphabetically by state)

VA Medical Center Birmingham, AL 35233	Page
Dynamic Biomechanics of Spinal Implants	257
Efficacy of Remote Treatment of Aphasia by TEL-Communicology	432

VA Medical Center Little Rock, AR 72206	Page
Electromyographic Incontinence Alert Device	346

VA Medical Center Phoenix, AZ 85012	
----------------------------------------	--

	Page		
Limb Viability: Vascular Reconstruction and Amputation Surgery	9	Voice and Speech Findings in Prospective Cochlear Implant Candidates	408
VA Medical Center Long Beach, CA 90822		VA Medical Center Washington, DC 20422	
	Page		Page
Identification of Optimal Amputation Level in Ischemic Limbs	10	Electroacoustical and Clinical Protocols for Evaluating Assistive Listening Devices	399
A New Technique in the Assessment and Treatment of Autonomic Dysreflexia	104	VA Medical Center Bay Pines, FL 33504	
Effects of Real-Time Biofeedback on Dysarthric Speech ..	436		Page
Evaluation of One-Way Air Flow Valve Prostheses in Decannulation Procedures for Chronic Tracheotomized Patients	443	The Influence of Mode of Stimulation on Naming Performance in Aphasia	433
VA Medical Center Martinez, CA 94553		Perceptual and Acoustical Characteristics of Tracheoesophageal Voice	436
	Page	VA Medical Center Gainesville, FL 32602	
An Auditory Prosthesis for Sensorineural Hearing Loss ..	410		Page
VA Medical Center San Diego, CA 92161		Quantitative Analysis of Total Hip Arthroplasty on Cadaver Pelvis Stress and Strain	76
	Page	Computerized Treatment of Acquired Reading Disorders: Treatment of Alexia and Agraphia	420
The Effect on Gait Using Various Ankle-Foot Devices	8	Augmentative Communication for Intensive Care Unit Patients	441
Implant Fixation by Postinsertion Pressurization of Polymethylmethacrylate	64	VA Medical Center Miami, FL 33125	
Electrical Stimulation of Fast and Slow Skeletal Muscle (with the National Institutes of Health)	211		Page
Structural and Functional Properties of Normal and Healing Ligaments	306	The Use of EMG Biofeedback and Functional Electrical Stimulation in Spinal Cord Injury	209
Structural and Functional Properties of Normal and Healing Ligaments (Project Extension)	307	Psychiatric Rehabilitation in Nursing Homes	443
VA Medical Center San Francisco, CA 94121		VA Medical Center Augusta, GA 30910	
	Page		Page
Diabetic Neurotropic Ulceration: Screening and Prevention Utilizing Aesthesiometry	8	Mechanism Based Treatments for Phantom Limb Pain	4
Optimization of Amputee Prosthesis Weight and Weight Distribution	34	Determination of Causes and Mechanisms of Phantom Pain (with the Dept. of Clinical Investigation of the U.S. Army)	11
Therapeutic Evaluation of the VA San Francisco Therapeutic Molded Shoe and Diabetic Risk Stratification	55	Evaluation of Psychophysiological Ways to Assess Chronic Low Back Pain (with the Dept. of Clinical Investigation of the U.S. Army)	326
Effect of Ligamentous Instability on Knee Joint Proprioception	259	Personal Computer System for Acoustic Measurements ..	405
Study of Bone Structural Response to Altered Loading ..	259	Effects of Manipulation of the Impedance of the Ear of Normal Subjects on Selected Indices of Auditory Function	406
VA Medical Center Denver, CO 80220		Threshold Sound Pressure Levels (SPLs) for the ER-3A Insert Earphone	406
	Page	Acoustic Vowel Measures Following Radiation Therapy to the Larynx	421
Implementation of Extended Physiological Proprioception for Prosthesis Control	45	VA Regional Office and VA Outpatient Clinic Honolulu, HI 96813	
The Application of Microcomputers for the Treatment of Aphasic Adults	334		Page
VA Medical Center West Haven, CT 06516		Computer Vision to Guide the Blind (with the Pacific International Center for High Technology Research)	394
	Page	Report on Phase I and Phase II: An Epidemiological Assessment of Disabled Veterans in Guam, American Samoa, and Hawaii	440
Clinical Application Study of Training Techniques and Devices for the Blind	389		

VA Medical Center
Iowa City, IA 52240

	Page
Assessment of the Swallow Reflex in Patients with Dysphagia	444

VA Medical Center and
Prosthetics Research Laboratory, Northwestern University
Chicago, IL 60611

	Page
CAD/CAM of Below-Knee Prosthesis: Program Studies ...	20
Computer-Aided Analysis of Below-Knee Prostheses Alignment	21
Computer-Aided Analysis of Below-Knee Socket Pressure	22
Improved Upper Limb Prosthetics Development Program	36
Design of Prehension Systems for Upper Limb Amputees	38
Below-Elbow Prosthetic System	42
Position-Servo Control of Upper Limb Powered Prostheses	44

VA Medical Center
North Chicago, IL 60064

	Page
Experimental Analysis of Response Elaboration Training in Aphasia	428

VA Medical Center
New Orleans, LA 70146

	Page
The Effect of Surgical Fit on the Biological and Mechanical Response to Porous Surfaced Implants	65
The Mechanical Properties of Porous-Coated Orthopaedic Alloy	66
Retrieval and Analysis of Orthopaedic Implants	67
Model to Study the Mechanical Behavior of Osteoporotic Bone	69
Effects of Treatment for Heterotopic Bone Formation on Biological Fixation	72

VA Medical Center
Baltimore, MD 21218

	Page
Clinical Evaluation of External Devices for Urinary Care of Incontinent Women	82

VA Medical Center
Boston, MA 02108

	Page
Human In Vivo Acetabular Pressure Movement	73
Use of Capuchin Monkeys as Aides for Quadriplegics	156
Direct Measurement of Loudness Recruitment in Hearing-Impaired Veterans (Project Extension)	402

VA Outpatient Clinic
Boston, MA 02108

	Page
Motor Control in Subjects with Clinical Disorders (with the Liberty Mutual Insurance Co.)	303
Direct Measurement of Loudness Recruitment in Hearing-Impaired Veterans	401

VA Medical Center
Brockton, MA 02401

	Page
All-Plastic Total Knee Replacement	80
Design of External Joint Assemblies (EJAs) Using CAD/CAM Techniques	80

VA Medical Center
West Roxbury, MA 02132

	Page
Hybrid Upper Extremity Orthoses for C5-C7 SCI Patients	127

VA Medical Center
Ann Arbor, MI 48105

	Page
Electrical Stimulation for the Prevention of Pressure Sores: Blood Flow Measurements	83

VA Medical Center
Columbia, MO 65201

	Page
The Application of Microcomputers for the Treatment of Aphasic Adults	334

VA Medical Center
East Orange, NJ 07019

	Page
Perception of Reverberation by the Hearing Impaired	401

VA Medical Center
Lyons, NJ 07939

	Page
Enhancement of Wound Healing, Using Synthetic Skin, Electrical Stimulation and Hyperbaric Oxygen Therapy	287

VA Medical Center
Reno, NV 89520

	Page
Drawing: Its Use as a Communicative Aid with Aphasic and Normal Adults	428

VA Medical Center
Castle Point, NY 12511

	Page
Determination of the Effects of Implant Interface Mechanics on Bone Remodeling (with the New York Dept. of Health)	63
Early Detection of Pressure Sores by Means of Biomedical Indicators	102
A Feasibility Study on Detection of Impending Pressure Sores Using Ultrasound	104
Seat Cushions for the Paralyzed	148

Rehabilitation R&D Progress Reports 1987

Testing of Design Parameters for a Prototype Piezoelectric Internal Fixation Plate (with the Walter Scott & Lyons Foundation and New York State Dept. of Health)	284
A Program for Evaluating the Dysvascular Patient	328
A Program for Evaluating the Dysvascular Patient (Project Extension)	330
VA Medical Center New York, NY 10010	
Development of the ISNY Below-Knee Flexible Socket System	24
Geriatric Prosthetics: Design and Development of an Improved Above-Knee Socket	31
EMG as Force-Feedback in Closed-Loop Functional Electrical Stimulation	233
Geriatric Prosthetics: Design and Development of an Improved Above-Knee Socket (Project Extension)	345
VA Medical Center Asheville, NC 28805	
Portable Motorized Standing Aid	238
VA Medical Center Cleveland, OH 44106	
Intramuscular Electrical Activation of the Diaphragm	211
Portable Functional Neuromuscular Systems for Upper Extremity Control (with the National Institute on Disability and Rehabilitation Research)	220
Quantitative Assessment of a Functional Neuromuscular Stimulation Motor Prosthesis for Restoration of Grasp in the Quadriplegic Hand (with the National Institute on Disability and Rehabilitation Research)	221
An Externally Powered, Multichannel, Implantable Stimulator for Control of Paralyzed Muscle (with the National Institutes of Health)	226
Functional Tasks Restored in Paralyzed Man Using Electronic Orthotics	231
Functional Tasks Restored in Paralyzed Man Using Electronic Orthotics (Project Extension)	232
VA Medical Center Dayton, OH 45428	
Fitness Improvements and Physiological Responses to FES Exercise	230
VA Medical Center Oklahoma City, OK 73104	
Gait and Energy Expenditure in Above-Knee Amputees: Differences Between Socket Types	30
VA Medical Center Portland, OR 97207	
Non-Auditory Factors Affecting Hearing Aid Use in Elderly Veterans	346
VA Medical Center Lebanon, PA 17042	
Role of Pressure Distribution Measurement in Diabetic Foot Care	53
VA Medical Center Philadelphia, PA 19104	
Measurement of Stratum Corneum Diffusional Conductance	1
Skin Blood Flow by Laser Doppler Velocimetry (LDV)	1
Comparison of Helium Flux, Xenon Washout, and Laser Doppler Velocimetry in Skin Blood Flow	2
Fluorometric Prediction of Canine Small Intestinal Viability Following Venous Occlusion	3
Oral Fluorescein in Patients	3
Oral Fluorescein in Animals	5
The Use of Quantitative Perfusion Fluorometry to Measure Relative Tumor and Liver Blood Flow After Transient Microembolization	5
Quantitative Perfusion Fluorometry as a Useful Adjunct to Determine the Healing of Lower Extremity Amputation	10
Patterns of Perfusion as Assessed by Quantitative Perfusion Fluorometry That Could Affect the Outcome of a Below-Knee Amputation	25
Myoelectrically Controlled Above-Knee Prosthesis (with the Gait Laboratory, Moss Rehabilitation Hospital)	32
Cosmetic Covers for Upper Extremity Prostheses (Male/Female)	37
Initial Stability of Orderly Oriented Wire Mesh Porous-Coated Implants	75
VA Medical Center (Highland Ave.) Pittsburgh, PA 15206	
Promoting Generalized Language Use: An Analysis of Treatment Strategies	427
VA Medical Center (University Dr.) Pittsburgh, PA 15240	
Ferrographic and Biochemical Analysis of Wear Particles in Human Joints	70
VA Medical Center Columbia, SC 29209	
Effectiveness of Shock Absorbing Materials in Reducing Heel-strike Forces in Walking (with the Bioengineering Alliance of South Carolina)	54
Absorbable Fixation Devices: Orthopaedic and Reconstructive Surgery (Pilot Study)	63
Relation of Computerized Axial Tomography (CAT) Scan Mineral Density to Mechanical Properties of Vertebrae (with the Bioengineering Alliance of South Carolina)	255
Prediction of Trabecular Bone Strength and Modulus by Computerized Axial Tomography (CAT) (with the Bioengineering Alliance of South Carolina)	256
Digital Techniques for Objective Analysis of Aural Acoustic Immittance	392

Artificial Intelligence Strategies for Orthopedic Clinical Decision Making (with the **Bioengineering Alliance of South Carolina**) 442

VA Medical Center
Memphis, TN 38104

Measurement and Prediction of Benefit from Amplification 419

VA Medical Center
Nashville, TN 37203

Functional Kinesiology of Knee Bracing 55
Pathokinesiology of Anterior Cruciate Ligament Deficiency 258
Bone In Vivo and In Vitro Stress and Strain Patterns 260

VA Medical Center
Dallas, TX 75216

Synthetic Bone Graft Materials in Segmental Defect Fractures 285
Noninvasive Assessment of Fracture Healing 286

VA Medical Center
Houston, TX 77211

Automated Fabrication of Lower Extremity Prosthetic Sockets 35
Evaluation of the Neutral Posture for Handicapped Utilizing Wheelchairs 138

VA Medical Center
Temple, TX 76501

Development of a Digital Hearing Aid and Computer-Based Fitting Procedure: Phase II 399
Development of Materials for Computer-Assisted Instruction in Lipreading 404

VA Medical Center
Richmond, VA 23249

Clinical Evaluation of the JHU/APL Robotic Arm 171
Basic Mechanisms and Rehabilitative Strategies for Presbycusis 409
Changes in Frequency Organization of the Cochlea During Aging 409

VA Medical Center and
University of Utah School of Medicine
Salt Lake City, UT 84132

Skeletal Aging and Disease in Failure of Hip Surface Replacement (with the **Div. of Orthopedic Surgery, Univ. of Utah School of Medicine**) 75

VA Medical Center
Seattle, WA 98108

Automatic Fabrication of Prostheses and Orthoses: Evaluation/ Demonstration of Roehampton CAD/CAM System 6
Automated Fabrication of Prostheses and Orthoses: Development of Prosthetic Shape Comparison and CAD Software 7
Automated Fabrication of Prostheses and Orthoses: Development of Prosthetic Socket Rectification Rules 7
Prosthetics Research Study Report 19
Diabetic Foot Ulcers: Quantifying the Effects of Nonsurgical Treatments 26
Lower Extremity Spasticity Following Spinal Cord Injury 118
Recovery Following Incomplete Spinal Cord Injury: An Animal Model (with the **University of Washington**) 118
UNISTIK Vehicle Controller: Safety, Reliability, and Human Applications 144
Circulatory and Mechanical Response of Skin to Compression Loading 288
Morphologic and Ultrasonic Analysis of Normal and Ischemic Human Wounds 289
Altered Collagen and Wound Metabolism in Nonhealing Diabetic Ulcers 290

VA Medical Center
Madison, WI 53705

Efficacy of Injectable Collagen to Correct Glottal Insufficiency 344
Pilot Study on the Efficacy of Injected Cross-Linked Collagen in the Treatment of Symptomatic Glottic Insufficiency 441

VA Medical Center
Milwaukee, WI 53193

Development of a Sensory Substitution System for the Insensate Foot 12
Age-Related Changes in Sensorimotor Performance 343

The Johns Hopkins University Applied Physics Laboratory,
Laurel, MD 20707

Robot Arm Work Station System for High Spinal Cord Injured Persons 176

NeuroMuscular Research Center
Boston University, Boston, MA 02215

New Motor Control Assessment Techniques for Evaluating Individuals with Severe Handicaps (with the **Liberty Mutual Insurance Co.**) 240
Biomechanical Modeling of the Lower Back 256
WATRACK - A New System for Studying Movement . . . 271
Muscle Fatigue and Back Pain (with the **Liberty Mutual Insurance Co.**) 303

Special Team for Amputations, Mobility, Prosthetics/Orthotics
VAMC, STAMP Program, 5901 E. 7th St., Long Beach, CA 90822

Sanford H. Anzel, M.D., and Herbert Kent, M.D., Directors

	Page
The Effect of Plantarflexion Bumper Stiffness in Single-Axis Prosthetic Feet	16
Gait Lab Analysis of Dynamic Elastic Response in Prosthetic Feet	17
Energy Cost Comparison of "Stored Energy" Prosthetic Feet with Solid Ankle Cushion Heel Prosthetic Feet	18
Functional Comparison of Single-Axis and Solid Ankle Cushion Heel Prosthetic Feet in the Dysvascular Below-knee Amputee	29
Biomechanical Evaluation of the Patellofemoral Joint Under Various Degrees of Fixed Rotational Deformities in the Femur	270

University of Texas Health Sciences Center at Dallas, Division of Orthopedics, Dallas, TX 75235

	Page
Myoelectric Analysis of Human Spine Function: Myoelectric Measurement of Human Muscle Endurance	325

University of Washington, Department of Orthopaedics, Seattle, WA 98195

	Page
Ligament Insertions: Relations in the Moving Knee (with the National Institutes of Health)	79

International Exchange of Experts and Information in Rehabilitation of the World Rehabilitation Fund, Inc.
400 East 34th St., New York, NY10016
Diane E. Woods, Director

VA Rehabilitation Research and Development Service

	Page
Technology Applications for Aphasia Rehabilitation: Lessons from Sweden, Poland, and The Netherlands	431

National Institute on Disability and Rehabilitation Research
U.S. Dept. of Education, 300 Maryland Ave., S.W., Washington, D.C.20202

National Science Foundation
1800 G St., N.W., Washington, D.C. 20550
Erich Bloch, Director

VA Rehabilitation Research and Development Service

	Page
Quantification of Mobility Performance for Functional Assessment, Diagnosis, and Therapy of Neuromuscular, Skeletal, and Synovial Joint Dysfunctions	263

The following reports represent research supported by VA Medical Center Core Funds or through other VA agencies.

VA/INTERAGENCY PROJECTS

Administration on Aging
330 Independence Ave., Washington, DC 20201

National Aeronautics and Space Administration
NASA Headquarters, Washington, DC 20546

National Institute on Aging
9000 Rockville Pike, Bethesda, MD 20205

National Institute on Disability and Rehabilitation Research
330 C St., S.W., Washington, DC 20201

VA Rehabilitation Research and Development Service

	Page
Integrated System for the Management of Wandering Behavior in the Memory-Impaired Elderly: An Interagency Report	347

Atlanta VA Medical Center Research Service
Decatur, GA 30033

	Page
Assessment of the Spatial and Temporal Characteristics of Vision as a Function of Age.	361

Birmingham VA Medical Center
Birmingham, AL 35294

	Page
Adaptation of the Amiga Personal Computer to the Visually Impaired User.	396

Dallas VA Medical Center
Dallas, TX 75216

	Page
Novel Pace Counter Design for Lower Limb Temporary Prostheses.	13
A Rehabilitation Shoe for the "At Risk Foot"	13
Objective Assessment of the Performance of Insert Materials in Diabetic Footwear	14

Department of Medicine and Surgery
VA Central Office, 810 Vermont Ave., N.W., Washington,
D.C. 20420

	Page
Hearing Impaired Blind Veterans	365

Health Systems Research and Development
VA Central Office, 810 Vermont Ave., N.W., Washington,
D.C.20420

	Page
Rehabilitation of Neurogenic Communication Disorders in Re- mote Settings	446

Hines VA Medical Center
Hines, IL 60141

R&D Core Funds

	Page
Inhibition of the Hyperreflexic Bladder: Preclinical Trials.	107
The Physical Correlates of Tactual Perception	367
A Portable Navigational Aid for Blind Persons.	393
Braille Teaching Aid with Synthetic Speech	397

Palo Alto VA Medical Center
Palo Alto, CA 94304

R&D Core Funds

	Page
Ultrasonic Head-Controlled Wheelchair and Interface (with the Paralyzed Veterans of America)	144
A Voice-Output Questionnaire Administrator.	365
A Robotic Hand Communication Aid for the Deaf-Blind (with the National Institute on Disability and Rehabilitation Research and the Smith-Kettlewell Eye Research Foundation).	375
Transparent Access to Sources of Computer-Based Information (with the Digital Equipment Corporation)	437

Salem VA Medical Center
Salem, VA 24153

	Page
Environmental Influences on Behavior of Patients with Alz- heimer's Disease.	362

Other Funding Organizations

AcroMed Corporation
3303 Carnegie Ave., Cleveland, OH 44115

	Page
Biomechanical Testing of Spinal Instrumentation Systems	261

Action Research for the Crippled Child
Vincent House, North Parade, Horsham,
West Sussex, RH12 2DA United Kingdom

	Page
Investigation into the Benefits of Upright Stance and Ambulation in the Severely Disabled	239

**American Academy for Cerebral Palsy and Developmental
Medicine**
2315 Westwood Ave., Richmond, VA 23230
John A. Hinckley, Executive Director

	Page
The Relationship Between Visual Perception and Social Per- ception in Cerebral Palsied Children	447

American Federation for Aging Research
725 Park Ave., New York, NY 10021

	Page
Finite Element Analysis of a Below-Knee Prosthesis.	26

American Occupational Therapy Foundation
1383 Piccard Dr., Rockville, MD 20850

	Page
Development of the Occupational Therapy Comprehensive Functional Assessment (OTCFA)	199

Boeing Computer Services
7755 E. Marginal Way So., Seattle, WA 98124

	Page
Independent Vocational Workstation for a Quadriplegic ..	180

Boston University
Boston, MA 02215

	Page
Muscle Fatigue and Respiratory Failure	304

CAFIR, University of Montreal
CP 6128 Succa
Montreal, Quebec, H3C 3J7 Canada

	Page
A Comparison of the Effectiveness of Flexible and Rigid Shoes in Relieving Pain at the Metatarsophalangeal Joint of Rheu- matoid Arthritis Patients	56

The Center for Independent Living
2539 Telegraph Ave., Berkeley CA 94704
Michael Winter, Director

Supported Employment for Youth with Learning Disabilities	Page 156	Commonwealth of Virginia Department of Rehabilitative Services, with the National Institute on Disability and Rehabilitation Research 4901 Fitzhugh Ave., Richmond, VA 23230 <i>Altamont Dickerson, Jr., Commissioner</i>	Page
The Center for Social Policy and Practice in the Workplace, Columbia University School of Social Work 622 West 113 St., New York, NY 10025 <i>Sheila Akabas, Director</i>	Page	Enhanced Understanding of the Economics of Disability	159
Promoting Rehabilitation Services and Policies Worksite-Based Employment Assistance Programs (EAPs) as Effective Advocates	157	Easter Seal Research Institute 1 Young St., Suite 2110, Toronto, Ontario, M5E 1E5 Canada	Page
Channel 10 Children's Medical Research Foundation of S.A. Gilberton 5081, South Australia	Page	The Development and Clinical Assessment of a Universal Wheelchair Controller System	146
A Study of Powered Wheelchair Controllers	146	Toward Further Development of a Seating System for the Physically Handicapped	151
A Comparative Evaluation of Special Seating for Severely Disabled Children	149	Evaluating the Effectiveness of Direct Client Intervention and Facilitator Training for Communication Intervention with Nonspeaking Physically Disabled Children	184
Development of a Trialable Ablution Unit Able to be Handled and Used by a Wheelchair User	158	Therapeutic Electrical Stimulation (TES) in the Rehabilitation of Children with Cerebral Palsy	213
Research into Design Requirements for Access by Children with Physical Disabilities	158	Validation of a Gross Motor Function Measure (GMFM) for Assessment of Outcome in the Treatment of Cerebral Palsy	241
Assessment of the Effectiveness of a Small, High Quality Speech Synthesizer in Augmenting the Communication of Non-Speaking Individuals	183	Design and Validation of a Subject/Instrument Interface to Allow Collection of Selected Pulmonary Function and Selected Metabolic Measures of Children with Cerebral Palsy (with the Variety Club of Ontario, Tent 28)	448
Chesebrough-Pond's Inc. Trumbull Industrial Park, Trumbull, CT 06611 <i>Dean Darryl Williams, M.D., Director</i>	Page	Edwin Shaw Hospital Foundation 1621 Flickinger Rd., Akron, OH 44312 <i>Daniel Church, Ph.D., Director</i>	Page
Evaluation of Pressures Applied by Elastic Dressings	331	Biomechanical Measurements for Quantitative Assessment and Diagnosis of Dysphagia	335
Clemson University, College of Engineering, Department of Bioengineering, Clemson, SC 29634	Page	Eye Research Institute/Retina Foundation 20 Staniford St., Boston, MA 02114	Page
Understanding Spasticity and the Effects of Rhizotomy Surgery	447	Model-Based Image Enhancement for the Visually Impaired	368
Cleveland Clinic Foundation Research Institute 9500 Euclid Ave., Cleveland, OH 44106 <i>Bernadine Healy, M.D., Director</i>	Page	Georgia Department of Human Resources and Center for Rehabilitation Technology, Division of Rehabilitation Services Georgia Institute of Technology, 400 Tenth St., N.W., Atlanta, GA 30332	Page
Computer-Aided Prescription of Specialized Seats for Wheelchairs	150	<i>Thomas Gaines, DRS Director; Richard Martin, CRT Director</i>	Page
Weightbearing Characteristics of Soft Tissues for Body Support Applications	151	Workstation Development for the Mobility Impaired	160
Comparison of Pressure Monitoring Systems	152	The Hospital for Sick Children Foundation 555 University Ave., Toronto, Ontario, M5G 1X8 Canada	
Comparative Evaluation of Body Support Systems for Tissue Pressure Distribution	240		
Evaluation of the Slide Board Exercise for ACL Rehabilitation	261		
Biofeedback System for Postoperative Hand Rehabilitation	279		

	Page
Assessment Protocol for Prescription of Powered Mobility Devices	147
Dynamic Positional and Electromyographic Monitoring of Sitting Posture (with the National Health Research and Development Programme, Dept. of Health and Welfare, Canada)	279
Protective Headwear for Disabled Children	449

Housing Trust of S.A.
Gilberton 5081, South Australia

	Page
Construction of a Home Unit for Live-In Trialing of Assistive Devices	161

Howmedica
359 Veterans Blvd., Rutherford, NJ 07070
David Fitzgerald, Director

	Page
Biomechanical Testing of a New Anterior Construct for Segmental Spinal Fusion	262

Hugh Mac Millan Medical Centre
350 Rumsey Rd., Toronto, Ontario M4G 1R8, Canada
Ruth Koheil, Assistant Director, Research Department

The Hugh MacMillan Medical Centre is a world renowned, special rehabilitation hospital and school serving physically disabled children and young adults to age nineteen. Individuals receive diagnosis, assessment, and treatment on an inpatient and outpatient basis.

	Page
Neofrakt versus Scotchcast in the Tone Reducing Ankle Foot Orthosis (Student Research Award)	57
A Systematic Analysis of Communicative Interaction Between a Nonspeaking Physically Disabled Child and a Speaking Peer: Pilot Study(Augmentative Communication Service)	182
Assessment and Prescription of Writing Aids for Physically Handicapped Children (Research Department)	193
Evaluating the Effectiveness of Direct Client Intervention and Facilitator Training in Communication Intervention with Nonspeaking Physically Disabled Children: Pilot Study	193
Inhibitive Casting as an Adjunct to Therapy in Children with Cerebral Palsy (Research Department Seed Fund)	313
Language Performance in Cleft Palate Adolescents (Student Research Award)	421
Assessing the Need for Management of the Neurogenic Bowel in the Pediatric Population (Research Department)	458

Innovative Research Programme/Aids for the Handicapped
Bisonspoor 3006, Maarssen, The Netherlands

	Page
Ergonomics of Manual Wheelchair Propulsion	140

Institute for Rehabilitation Research
6432 CC Hoensbroek, The Netherlands

	Page
Spartacus and Manus: Telethesis Developments in France and The Netherlands	178

Japanese Ministry of Education
3-2-2, Kasumigaseki, Chiyoda-ku, Tokyo 100, Japan

	Page
Development of a Posture Sensor and Sensory Biofeedback System for Use in Gait Training of the Locomotion Disabled	271

Liberty Mutual Insurance Company
175 E. Berkeley St., Boston, MA 02215
Carlo J. De Luca, Director, NeuroMuscular Research Center

	Page
Measurements of Postural Sway	272
A Model for Postural Sway	272
The Myoelectric Signal Decomposition Technique	297
Surface Electrode Design	297
Myoelectric Signal Quality Analyzer	298
Decomposition of Surface-Detected Myoelectric Signals	299
Cross-Talk Between Myoelectric Signals of Adjacent Muscles	300
Muscle Force Output During Voluntary Contractions	300
Synchronization of Motor Unit Discharges	301
The Common-Drive Principle of Motor Unit Control (with the National Institute on Aging)	302
Muscle Fatigue and Myoelectric Signal	305
Muscle Fatigue Monitor	305
Motor Unit Properties Investigated by Voluntary and Electrically Elicited Contractions	306
Long-Term Effects of Topical Anesthesia in Stroke Patients: Measurement and Analysis of Neurophysiological Reflexes	336

Lothian Health Board
11 Drumsheugh Gardens, Edinburgh EH3 7QG, Scotland

	Page
Research into a Modular Prosthetic Development for the Upper Limb	39
A "Smart" Controller for Electric Wheelchairs (with the Scottish Education Department)	148
The Clinical Application of Gait Analysis (with the Spastics Society, the University of Edinburgh, the Women's Royal Voluntary Service, and Ferranti P.L.I.)	273
Edinburgh Unilateral External Fracture Fixation Device	291

Louisiana State University Medical Center, Department of Orthopaedics, Bioengineering Laboratory
1542 Tuland Ave., New Orleans, LA 70112

M. Solomonow, Ph.D., Director of Bioengineering

	Page
The LSU Reciprocating Gait Orthosis	57
Development of Design Methodology for Anterior Cruciate Ligament-Deficient Knee Braces	58
Evaluation of Knee Performance After Various Orthopaedic Procedures	80
Comparative Electromyography of Orderly and Reverse Recruitment Studied with FES.....	214
Development of a Stimulation System for Manipulating Muscle Force with Various Firing Rate and Recruit Control Strategies (with the National Science Foundation).....	214
Development of an Improved Walking System for Paraplegics with FES Adjunct to the LSU Reciprocating Gait Orthoses	235
Biomechanics and Electromyography of Anterior Cruciate Ligament (ACL)-Deficient Knees	263
Knee Biomechanics of Athletes with High Risk Exposure to ACL Injury.....	263

Louisiana State University Medical Center, Department of Orthopaedic Surgery
1501 Kings Highway, Shreveport, LA 71130

	Page
Evaluation of Osteoporosis by Ultrasound and CAT-Scan	314

Milly Aphthorp Charitable Trust
Cambridge University, Cambridge, United Kingdom

	Page
A Potential Application in Early Education and a Possible Role for a Vision System in a Workstation Based Robotic Aid for Physically Disabled Persons.....	179

The Ministry of Community and Social Services (COMSOC)
Government of Ontario, Toronto, 80 Grosvenor St., Ontario, M7A 1E9 Canada

	Page
The Development and Clinical Evaluation of a Radio Frequency Linked, Computer-Based, Voice-Controlled Workstation for the High Level Quadriplegic	186
Toward Development of a Protocol for Assessing the Communicative Interaction Skills of Nonspeaking Severely Handicapped Individuals.....	187

Mississippi State University, Rehabilitation Research and Training Center on Blindness and Low Vision
P.O. Drawer 6189, Mississippi State, MS 39762

William Graves, Ph.D., Director

(with the **National Institute on Disability and Rehabilitation Research**)

	Page
Expansion and Enhancement of the National Blindness and Low Vision Database.....	373
Time Use and Resource Allocations of People with Visual Disabilities: Assessment Instrumentation (also with the American Foundation for the Blind)	374
Development and Validation of a Work Environment Visual Demands (WEVD) Protocol.....	375
Sensory Aid Technology: A Career Development Intervention Strategy for Blind and Visually Impaired Persons.....	378
Learning Styles and Effective Teaching Technologies for Enhancing the Employment of Deaf-Blind Youths	379
Identification of Job Tasks and Management Practices Performed by Blind and Visually Impaired Persons in the Operation of the Business Enterprise Program	380
Identification of Work Assessment Technology Needs....	380
Identification and Classification of the Career Transition Problems of Blind and Visually Impaired Persons Employed as Professionals, Managers, or Technicians.....	381
Modification and Adaptation of the Vocational Education Readiness Test for Blind/Severely Visually Impaired Individuals	381

Moss Rehabilitation Hospital
12th St. and Tabor Rd., Philadelphia, PA 19141

Gary Goldberg, M.D., Chairman, Staff Research Committee
The Moss Rehabilitation Center of the hospital has a long tradition of involvement in rehabilitation research and development that includes work in innovative prosthetic design, gait analysis, neuropsychology, motor control, and clinical neurophysiology. The facility combines advanced laboratory capabilities in functional diagnostic studies (gait lab, motor control analysis, evoked potentials, electromyography) with program-oriented inpatient clinical services (stroke, head injury, amputee, musculoskeletal trauma, arthritis, and pediatrics) functioning in the context of comprehensive medical rehabilitation. The Hospital Board funds a program of internal research and additional funds supplied through the Solon Foundation are used to support research relevant to the rehabilitation of persons with traumatic brain injury.

	Page
Design and Construction of a Bicycle Attachment for Conditioning of Below-Knee Amputees in the Early Postoperative Stage.....	27

National Eye Institute
Bldg. 31, Rm. 6A03, Bethesda, MD 20892
Carl Kufper, Ph.D., Director

	Page
Model-Based Image Enhancement for the Visually Impaired	368
Functional Vision and Clinical Tests in Low Vision.	368
Electronic Braille Page Output Device Using National SMA.	369
Sonar Sensory Substitution—Spatial Behavior in the Blind	369
Analysis of Navigation Without Sight	370
Psychophysics of Reading—Normal and Low Vision.	370
Prediction of Symbol Recognition in Low Vision Patients	371
Profile of Visual Function in Low Vision Patients	371
Visual Tests for Patients with Central Scotoma	372
Low Vision Reading: Optimizing Visuo-Motor Performance	372

National Health Research and Development Programme,
Dept. of Health and Welfare, Tunney's Pasture, Ottawa, Ontario, K1A 0K9 Canada

	Page
Design Modification to the Metatarsal Break of the SACH Prosthetic Foot (with the War Amputees of Canada)	14
Toward Development of a Universal Modular Wheelchair Tray for Communication, Mobility and ADL (with The Hospital for Sick Children Foundation).	188
The Effects of Proximal Tibial Osteotomy and Tibial Tubercle Elevation on Knee and Ankle Joint Loading (with the Physician's Services, Inc. Foundation of Ontario, Canada) . .	273
Monitoring Respiratory Patterns and Their Coordination with Swallowing in Cerebral Palsy.	449
Effects of Relaxed Breathing and Biofeedback on Bronchospasm in Chronic Asthma	450

National Fund for Research into Crippling Diseases
Vincent House, North Parade, Horsham, W. Sussex RH12 2DA, United Kingdom

	Page
Ambulatory Orthoses for the Severely Disabled: A Comparative Study.	58

National Institute on Disability and Rehabilitation Research
U.S. Dept. of Education, 300 Maryland Ave., S.W., Washington, D.C. 20202.
Richard R. Leclair, Acting Director

Established by the 1978 amendments to the Rehabilitation Act, the National Institute on Disability and Rehabilitation Research (NIDRR), formerly the National Institute of Handicapped Research, is responsible for managing a comprehensive program of disability-related research and training for professionals who provide services and conduct research. NIDRR's

mandate encompasses all major areas of applied research, such as medicine (including basic medical research); vocational rehabilitation; children, families, and other areas of psychosocial research; rehabilitation engineering; and information dissemination. All disabilities and age groups are at least potentially included in NIDRR research endeavors. The ultimate goal of NIDRR-sponsored projects is to enhance the independence of disabled persons and facilitate their full integration into all aspects of community life.

In addition to the projects reported below, NIDRR co-sponsors research with other organizations reporting in this publication, which is noted appropriately in this index and in the progress reports text.

	Page
Improvement of Body-Powered Upper Limb Prostheses . . .	40
Extended-Limb Prostheses	45
An Electric Artificial Limb for Children Without Limbs . .	46
Quantification of the Functional Capability of Upper Extremity Amputees	46
Activities of the Georgia Regional Spinal Cord Injury Center	86
On the Reduction of Energy Requirements for Crutch Ambulation by Paraplegics	86
Retrospective Analysis of the National Spinal Cord Injury Care System Database	87
New England Regional Model Spinal Cord Injury System. .	88
Effects of Nutritional Intervention During the Acute Phase of Spinal Cord Injury	89
Clinical Considerations Regarding the Penile Implant in Patients with Spinal Cord Dysfunction	90
Development of a Prospective Multi-Center Database for Head Injury Utilizing the Data Collection and Analysis Experience of the Model Regional Spinal Cord Injury Care Systems and the National Spinal Cord Injury Statistical Center	91
Assessment of Tendon Transfer Surgery in the Tetraplegic Upper Extremity	92
Psycho-Social Adjustment of Persons with Combined SCI and Closed-Head Injury: A Longitudinal Investigation	93
Effect of Intermittent Catheterization on Renal Stone Formation in Spinal Cord Injury Patients	108
Incidence, Characteristics, and Clinical Significance of Anemia in Patients with Spinal Cord Dysfunction	108
Pain Secondary to Gunshot Wound During the Initial Rehabilitation Process in Spinal Cord Injury Patients.	109
Didronel in the Prevention of Heterotopic Ossification Following Spinal Cord Injury: Determination of an Optimal Treatment Schedule	110
Natural History and Clinical Course of Urinary Tract Complications in Patients with Spinal Cord Dysfunction	111
Pathologic Effects of Recurrent Bacteriuria in Patients with Spinal Cord Dysfunction	112
Drug Effects on Bladder Smooth Muscle Contractility. . .	113
Man-Machine Interface for Upper Limb Neural Prostheses.	131
A Model for Optimization of Wheelchair Lever Propulsion (Field Initiated Research Program)	140

Wheeled Mobility and Improved Seating Systems (Rehabilitation Engineering Center Program).....	153
Documenting and Utilizing Programs that Provide Community Adjustment and Independent Living Services for Persons with Spinal Cord Injury	161
An Operational Definition of Independence	162
The Definition of "Peer": Consumer Perspectives and Significance in the Delivery of Counseling Services	163
Parameters of Independent Living Programs: A Longitudinal Study	163
Independent Living in Rural Areas: A Longitudinal Study	164
Production and Satellite Broadcast of Self-Help Videotapes for the Handicapped.....	165
Development of Design Criteria and Performance Standards for Barrier-Free Environments.....	166
Small Robot Arm in the Workplace to Aid in the Employment of Severely Physically Disabled Persons (with the Wichita Rehabilitation Engineering Center).....	181
PACA: Portable Anticipatory Communication Aid (with the Easter Seal Research Foundation).....	188
Available Motions of Hand, Mouth, and Head Stick Users: Applications to Keyboard Designs.....	189
International Compatibility Standards for Electronic Communication and Interface Devices.....	190
Computer Accessibility: Support of the Industry/Government Initiative	191
Improving Management of Vocational Rehabilitation Services.....	200
Progress Report for the PEER Regional Network	201
Advances in Psychosocial Rehabilitation	203
Value of Electrical Stimulation on Fertility in Male Patients with Spinal Cord Dysfunction	215
Miniature Sensor for Two-Degree-of-Freedom Position Transduction.....	223
Sensory Augmentation for FNS Upper Extremity Prostheses (with the National Institutes of Health).....	224
Preclinical Research in Neuromuscular Diseases and Muscle/Nerve Biology	242
Clinical Research in Neuromuscular Diseases	243
Mobile Assessment Laboratory.....	244
Rehabilitation Management of Neuromuscular Diseases Research and Training Center, University of California at Davis.....	244
Computer-Assisted Driver Assessment System	245
Psychometric and Performance Predictors of Driving Ability	246
Small-Scale Vehicle for Driver Assessment/Evaluation and Training	246
Development of a Uniform National Data System for Medical Rehabilitation	247
Predictive Assessment in Prescription of Functional Aids for the Motor Disabled.....	248
Quantitative Measures for Assessing Therapeutic Effectiveness	274
A Telemetric Data Acquisition and Processing System for Biofeedback Training and as a Diagnostic for Human Movement Training.....	275
Enhancement of Ulcerated Tissue Healing by Electrical Stimulation (with the Slovene Research Community, Ljubljana, Yugoslavia)	291
Arthritis Rehabilitation Unit	315
Impact of Arthritis Self-Care for Rural Persons	315
Endurance Training with Management of Fatigue in Rheumatic Arthritis and Systemic Lupus Erythematosus	316
Benefit and Cost Comparison Between a Coordinated Team Care Approach and a Traditional Office Based Approach to Outpatient Management of Rheumatoid Arthritis	324
Low Back Pain Studies	326
Computer-Aided Device Evaluation	337
Development and Evaluation of a Videotape Teaching Module for Nursing Students in the Clinical Setting (with the Genesis Foundation, Rhode Island)	337
Early Intervention with Globally Aphasic Stroke Patients Using a Computerized Visual Communication Technique.....	338
Work Disability, Disability Management and the Older Worker	348
An Optimal, Inexpensive Text Entry System for the Orthopedically and Neurologically Disabled.....	373
The Evaluation of Low Vision Aids and Prediction of Visual Performance	377
Enhancing the Reading Skills of Low Vision Individuals with Macular Loss	397
Transition Study of Persons with Hearing Impairments	411
Technology for Sensory Devices for Deaf and Severely Hard of Hearing People.....	412
Project PALS (Places with Assistive Listening Systems)	413
The Use of Microcomputers in Diagnosis and Rehabilitation of Adult Aphasic Individuals	422
Finance of Medical Rehabilitation Services: Interim Report on the Mary E. Switzer Distinguished Research Fellowship in Medical Rehabilitation Finance	451
Information Dissemination in Communication, Control, and Computer Access (with the University of Wisconsin at Madison and the College Hill Press, Little, Brown, and Co.)	452
Industry-Based Employee Assistance Program.....	453
Uses and Potential Uses of Information Technology by Rehabilitation Agencies	454
Disability Management and Rehabilitation: An Analysis of Programs, Costs, and Outcomes	455

National Institutes of Health

900 Rockville Pike, Bethesda, MD 20892

Dr. James Wyngaarden, Director

	Page
Comparison of Feedback Controllers for Functional Neuromuscular Stimulation	15
A Study of the Range of Motion of Human Fingers with Application to Anthropomorphic Designs (Nursing Home Program Project).....	42
Control of Metrical and Timing Precision in Human Movement	48
Two-Degree-of-Freedom, EPP-Based Arm Prosthesis for Above-Elbow Amputees	48
Complications of Cognitive Dysfunction in Spinal Cord Injury	94

Evaluation of Shoulder Position as a Command Control Source	95	Stroke Clinical Center Grant: Remediation of Left-Sided Neglect	339
A Center for Acute Spinal Cord Injury: Epidemiology and Economic Costs of Spinal Cord Trauma	96	Treatment of Affective Deficits in Stroke Rehabilitation	339
Body Composition and Nutrition in Spinal Cord Injury	96	Rehabilitative Software for Head Trauma Victims	340
The Neurite-Promoting Activity of the Basement Membrane Protein Laminin (National Cancer Institute)	119	Subthreshold Memory Phenomena	340
Artificial Sensory Transducers (Neural Prosthesis Program, National Institute of Neurological and Communicative Disorders and Stroke)	131	Precursors of Stroke Incidence and Prognosis	341
Program in Social and Independent Living Skills	201	Perceptual Retention and Age	349
A Multichannel Biotelemetry System	215	Geriatric Medicine Academic Award	349
Mechanism of Torque Generation: Implications for Stimulation Therapy	217	Studies in Idiopathic Normal Pressure Hydrocephalus	350
Artificial Sensory Transducer	225	Respite Care for Older Adults: A Prototype	350
Implantable Systems for Stimulation of Skeletal Muscle	226	Epidemiology of Cardiovascular Diseases in the Elderly	351
Elbow Control in the C5-C6 Quadriplegic Using Functional Neuromuscular Stimulation (with the National Institute on Disability and Rehabilitation Research)	227	Does Improvement in Mortality Mean Better Health?	351
Analysis and Development of Coordination Programs for Hand Grasp in the Tetraplegic Using Functional Neuromuscular Stimulation	228	The Community Adaptation of Mildly Retarded Persons: The Lives and Needs of Aging Mentally Retarded Persons	352
Feedback Control of Hand Grasp During Functional Neuromuscular Stimulation	236	Senile Dementia: Natural History	352
Prospective Study of Factors in Back Pain Disability	249	Learned Modification of Visceral Function in Man	352
Regaining Functional Abilities After Hip Fracture	250	Geriatric Medicine Academic Award	353
Segmental Bone and Joint Replacement After Tumor Resection	266	Falls in the Elderly: Causes and Reduction	353
Biomechanics of Metastatic Defects in Bone	267	Improving Recovery from Cardiac Surgery	354
Feasibility Study: Evaluation of Total Knee Replacement by Gait Analysis	276	Cancer Control Science Program: Fox Chase Cancer Center—Cancer Education and Management for Patients	354
Acceleration of Fracture Healing by Electrical Fields	292	The Treatment of Acute Illness in Nursing Homes	355
Exercise-Induced Adaptations of Skeletal Muscle Grafts	302	Research in Mental Retardation: Elderly Mentally Retarded—Population Description and Service Needs	355
Factors Limiting the Tactile Perception of Form	310	Older ESRD Patients: Rehabilitation and Quality of Life	356
Neural Pathways Involved in Tactile Discrimination	311	Illness Cognition and Coping in the Elderly	357
Multipurpose Arthritis Center: Community Component—Coping Responses to Rheumatoid Arthritis	317	Profile of Visual Function in Low Vision Patients	357
General Clinical Research Center: “Riadura” and NSAID in Rheumatoid Arthritis Treatment	317	The Behavioral Context of Incontinence in the Elderly	358
Multipurpose Arthritis Center: Professional Education in Sexual Rehabilitation of Arthritis Patients	317	Teaching Nursing Home: Modification of Exercise Capacity in the Elderly	358
Multipurpose Arthritis Center: Education Component—Arthritis Patient Education Model	318	Geriatric Medicine Academic Award	359
National Arthritis Data Source (ARAMIS)	319	Geriatric Dentistry Academic Award	359
Multipurpose Arthritis Center: Stanford, CA	319	Cutaneous Mechanoreceptor System	360
Northeast Ohio Arthritis Center Support: Legal Aspects of Chronic Illness—A Study of Arthritis Patients	320	Morbidity Risk Assessment in the Elderly	360
Multipurpose Arthritis Center: Community Component—Arthritis Impact Measurement Scales	321	Cooperative Group Outreach Program (ECOG)	361
Occupational Role Dysfunction in Illness: Comparisons with Normative Data	321	Cutaneous Pattern Perception	382
Multipurpose Arthritis Center: Problem-Oriented Educational Program for Arthritis Using Aerobic-Type Exercise	322	AKL Spatiotemporal Representation in a Tactile Aid for the Deaf	414
Study of Behavioral Aspects of Rheumatoid Arthritis	322	Speech Perception Studies—Bimodal and Developmental	414
UCSF Multipurpose Arthritis Center: Community Component—Studies Using a Panel of Rheumatoid Arthritis Patients	323	Tactile Communication of Speech	415
Postoperative Thromboembolism in Surgical Patients	332	Cutaneous Communication Aids for the Deaf	415
		Rehabilitation Strategies for the Hearing Impaired	416
		Reading and Writing Skills in the Congenitally Deaf	416
		Factors Predictive of Reading and Writing Skills in the Congenitally Deaf	416
		Development of a Wearable Vibrotactile Aid: Phase II	417
		The Role of the Haptic System in Communication	417
		Development of a Cochlear Prosthesis	418
		Wearable Multipoint Opto-Tactile Transducer for the Deaf or Blind	418
		Basic and Applied Studies of Tactile Perception	418
		The Acquisition of Morphological Processes in American Sign Language (ASL)	423
		Communication in Aphasia and Other Organic Disorders	434
		Recovery from Aphasia in Stroke	434

Rehabilitation R&D Progress Reports 1987

Neuropathophysiology of Speech Motor Impairments438
Structure and Acquisition of American Sign Language . . .439
Epidemiological Study of Pain.456
A Neurosensory Interdisciplinary Research Program: Tactile
Stimulator Development.457

National Science Foundation
1800 G St., N.W., Washington, D.C. 20550
Erich Bloch, Director

The Bioengineering and Research to Aid the Handicapped (BRAH) program of the National Science Foundation provides funding for fundamental academic engineering research relevant to the medical needs of society. The program emphasis includes findamental research that will support the emergence of medical-engineering technologies, especially technologies with the potential to become medically valuable within ten years. New activities in the BRAH program include cooperative agreements with other agencies, undergraduate engineering design initiatives, and cross-disciplinary group research grants.

	Page
Investigation of the Optimal Loadbearing Characteristics of Patellar Tendon-Bearing (PTB) Prostheses	28
Quantification Functional Assessment of Control Systems for Elbow Prostheses (with the Whitaker Foundation)	49
EMG Force Models in Muscles with Various Firing Rate and Recruitment Strategies	217
The Use of EMG as Force Feedback in Closed-Loop Electrical Stimulation System.	217
Control of Joint Motion With Synergistic Stimulation of Its Agonist/Antagonist Muscles.	218
A Comprehensive, Quantitative, Predictive Model of the Human Knee Joint	267
Biomechanics of Joint Motion (with the LSU Medical Center, Department of Orthopaedics)	268
The Frequency Response of Skeletal Muscles: Dependence on Control Strategies and Fiber Types	298

Natural Sciences and Engineering Research Council of Canada, Ottawa, Ontario K1A 1H5 Canada

	Page
A Microprocessor-Controlled Prosthesis with Extended Physiological Proprioception (with the Royal Ottawa Hospital and the University of Ottawa)	51
Kinematics of the Ankle and Subtalar Joint	269

Neil Squire Foundation
46-412 Lytton, North Vancouver, British Columbia, Canada

	Page
Manipulative Appliance Development in Canada: Neil Squire Foundation Project.	179

NeuroMuscular Research Center
Boston University, 44 Cummington St., Boston, MA 02215
Carlo J. De Luca, Director

	Page
The Biomechanics of Flat-Feet Running.	59
Gross Motor Attainments in Eleven to Fourteen-Year-Old Children with Down's Syndrome.	251
Muscle Fatigue and Respiratory Failure(with Boston University School of Medicine Pulmonary Center).	304
Sensorimotor Interactions in Motor Unit Control.	341

Neuroscience and Aging Institute, Loyola University, Stritch School of Medicine, 6525 North Sheridan, Chicago, IL 60626

	Page
Surface Sacral Stimulation for Bladder Management of Patients with Spinal Cord Injury	114

Northern Ireland Prosthetic Orthotic and Aids Service
Dept. of Health and Social Services, Dundonald House, Upper Newtownards Rd., Belfast, Northern Ireland

	Page
Experimental Investigation of Joint Prosthesis Fixation.	6
Assistance of Upper Limb Mobility	59
Clinical Gait Recording System.	277
Mechanics of Rising from the Seated Position	280

Office for Life Science Promotion of the Institute of Physical and Chemical Research, Agency of Science and Technology, Japanese Government
8-1, Kawada, Shinjuko, Tokyo 162 Japan

	Page
Development of a Powered Orthosis for Lower Limbs	60

Ontario Ministry of Education
900 Bay St., Toronto, Ontario, M7A 1L2 Canada

	Page
Towards Universality of Access to Information: Systems Software to Aid Access to Microcomputers by Physically and Multiply Disabled Students	185
Software Development: Blissbook (Exemplary Software Project)	398

Orthokinetics Research Foundation
5 Sedgemoor Ct., Williamsville, NY14221
Mo Neeman, Ph.D., and Henry J. Neeman, B.S., Co-Directors

	Page
Orthokinetic Orthoses: Clinical Efficacy Study in Non-Drug Analgesia of Post-Trauma Chronic Pain	251

Paralyzed Veterans of America, Spinal Cord Research Foundation

801 18th St., N.W., Washington, D.C. 20006

R. Jack Powell, Executive Director

The Spinal Cord Research Foundation (SCRF), formerly the Technology and Research Foundation, was established by the Paralyzed Veterans of America in 1975. SCRF is a modest-sized foundation which funds research projects and fellowships relevant to spinal cord injury. In addition to sponsoring basic research that will increase scientific knowledge toward a cure for spinal cord injury, SCRF also funds research that deals with applied medical, psychosocial, and technological areas of importance to persons with spinal cord injury.

	Page
Neurochemical Correlates of Autonomic Hyperreflexia in an Animal Model.....	96
The Health and Functional Status of Aging SCI Persons: A Feasibility Study Using Cases from Stoke Mandeville Hospital	98
An Implantable Sensor for Two-Degree-of-Freedom Position Transduction.....	102
Central Nervous System Regeneration in Adult Mammals: A Study of Inappropriate Terminal Axonal Contacts	120
Immunocytochemical Analysis of Localized Extracellular Proteolysis During Neuronal Development.....	120
Regeneration of Spinal Projection Neurons in a Peripheral Nerve Environment	121
Rapid Neuronal and Glial Changes in the Spinal Cord Following Injury	122
Effect of a GABA Agonist and a GABA Antagonist on Motor Recovery Following Subtotal Spinal Cord Lesion.....	123
Spinal Cord Synaptogenesis in Response to Deafferentation and Alterations in Nerve Growth Factor	123
A Study to Determine If Localized Extracellular Proteolysis is a Requirement for Successful Regeneration of Nervous Tissue	124
Modulation of Protein Phosphorylation in a Regenerating CNS Tract	125
Dorsal Root Axonal Regeneration in Adult Glial Deficient Mammalian Spinal Cord.....	125
Action and Metabolism of TRH in the Spinal Cord	126
International Symposium on Neural Regeneration	127
Closed-Loop Control of Functional Neuromuscular Stimulation Using Implantable Force Sensors	218

Politecnico di Torino

Center for Study, 24C Duca Abruzzi, Torino, Italy

Lelio Stragiotti, Director

	Page
Neuromuscular Stimulator with EMG Pickup Circuitry ...	219

Poona District Leprosy Committee

Manish, 2nd Floor, Flat #35, 2-A, Moledina Road, Pune-411 001, India

Dr. Jal Mehta, Hon. President

	Page
Management of Tarsal Disintegration in Leprosy	15
A New Approach in Muscle Training to Rehabilitate the Hand in Leprosy	280
A Study on Disintegration of Carpal Bones in Leprosy ...	292
Graded Weightbearing in Tarsal Disintegration in Leprosy	293
A New Approach in the Relief of Pain of Leprous Neuritis.....	311
Treatment of Leprous Neuritis by Perineurial Steroid Injection	312

REACH (The Association for Children with Artificial Arms)

13 Park Terr., Crimchard, Chard, Somerset, England

John Bruce, General Secretary

	Page
Development of a Cosmetic Functional Prosthesis for Children	41

RGK Foundation of Austin, TX

2815 San Gabriel, Austin, TX 78705

	Page
An Innovative Approach to Continuing Health Care Education (with the College of Engineering, Clemson University) ...	458

Rehabilitation Institute of Chicago

345 East Superior, Chicago, IL 60611

	Page
Chemical Dependence and Spinal Cord Injury Outcome (with the PVA Spinal Cord Research Foundation, National Institute on Disability and Rehabilitation Research, and National Institute on Alcohol Abuse and Alcoholism)	99

Rehabilitation Research and Training Center on Spinal Cord Dysfunction

University of Alabama at Birmingham, Birmingham, AL 35294

with the National Institute on Disability and Rehabilitation

	Page
Outcome Studies Pertinent to the National Model Spinal Cord Injury System.....	101
Neuroaugmentive Procedures for Modification of Abnormal Motor Control in Patients with Spinal Cord Injury.....	115
Effects of Spinal Cord Injury on Drug Metabolism (also with the Paralyzed Veterans of America)	115
Collagen Dysfunction in Quadriplegia (also with the Paralyzed Veterans of America Spinal Cord Research Foundation).....	116
Vocational Evaluation for Quadriplegics with a High School Education or Less	132
Development of a Reconditioning Exercise Program for Patients with Paraplegia	133
Longitudinal Assessment of the Utilization of Upper Extremity	

Assistive Devices Prescribed for the Spinal Cord Injured Quadriplegic 134

Longitudinal Assessment of Physical Therapy Factors in the Rehabilitation Process That Affect the Quality of Life of Persons with Spinal Cord Injury 135

Documenting and Utilizing Programs Which Provide Community Adjustment and Independent Living Services for Persons with Spinal Cord Injury 136

Assessment, Development, and Clinical Applications of Strategies to Coordinate Services for Spinal Cord Injured Clients After Discharge 137

Rehabilitation Centre (formerly Royal Ottawa Regional Rehabilitation Centre)
505 Smyth, Ottawa, Ontario K1H 8M2, Canada

Page

Infant Crib for Use by Wheelchair-Bound Parents (Royal Ottawa Hospital) 167

Systems to Enable Physically Handicapped Persons to Board Inter-city Buses (Royal Ottawa Hospital with the Transport Canada)..... 169

A Robot Feeder (Royal Ottawa Hospital with the Kinnear Foundation)..... 177

Rehabilitation Services Administration
U.S. Department of Education. 300 Maryland Ave., S.W., Washington, D.C. 20202

Page

CALVIN: A Robot Control Language for Rehabilitation Robotics 181

Research Centre for the Education of the Visually Handicapped
University of Birmingham, Selly Wick House, 59 Selly Wick Rd., Birmingham B29 7JE, England

Page

Normative Data for Assessing the Manual Dexterity of Visually Handicapped Adults in Vocational Rehabilitation..... 382

Research Programme on Quality and Functionality of Aids for the Handicapped
Department of Functional Anatomy, Faculty of Human Movement Sciences, The Free University, P.O. Box 7161, 1007MC, Amsterdam, The Netherlands

Page

Functionality and Durability of Manually-Propelled Wheelchairs 141

Robert Wood Johnson Foundation
P.O. Box 2316, Princeton, NJ 08543

Page

Computerized Task Guidance for Cognitively Impaired Persons 166

COGORTH: Cognition Orthosis Programming Language.. 195

Royal Institute of Technology
P.O. Box 70014, Stockholm S-100 44, Sweden

Gunnar Brodin, Director

Page

Speech Transmission Laboratory Reports 424

Science and Engineering Research Council
Polaris House, N. Star Ave., Swindon SN2 1ET, United Kingdom

Page

The Quantitative Assessment of Knee Orthoses for Control of Ligamentous Instability 253

A Survey of the Current Clinical Use of Gait Analysis in the United Kingdom..... 253

Ground Reaction Torque and Subtalar Joint Function ... 269

Scottish Home and Health Department, Committee for Research for Equipment for the Disabled
St. Andrews House, Regent Road, Edinburgh EH1 3DE, Scotland

Page

The Use of CAD/CAM in the Design and Development of a Range of Prosthetic Components for the Upper Limb ... 38

Further Research into the Use of Room Temperature Vulcanizing (RTV) Silicone Rubber as a Cosmetic Glove Material for Upper Limb Prostheses 39

Multi-Adjustable Forearm Support Walker..... 168

Walker for the Young Cerebral Palsied Adult..... 168

Matching of Computers and Interfaces to the Needs of Tetraplegic Patients..... 183

Physiological Benefits of Electrical Stimulation of Paralyzed Muscle 236

Smith-Kettlewell Eye Research Foundation
2232 Webster St., San Francisco, CA 94115

Arthur Jampolsky, M.D., and John Brabyn, Ph.D., Co-Directors

Page

Sensory Aids for the Blind and Visually Impaired (with the National Institute on Disability and Rehabilitation Research)..... 383

Special Children's Center, Inc.
21 Wilkins Road, Ithaca, NY 14850

Roger R. Sibley, Executive Director

Page

Talus Control Ankle Foot Orthosis: A New Design 60

Anterior versus Posterior Walkers for Children with Cerebral Palsy: A Gait Analysis Study..... 254

Comparison of Floor Sitting and Wedge Kneeler: Their Effects on Posture and Upper Extremity Range of Motion in Children with Cerebral Palsy 281

Texas Department of Mental Health and Mental Retardation
909 W. 45th St., Austin, TX 78711

Gary E. Miller, M.D., Director

Page

Rehabilitation Engineering Center 168

Tufts New England Medical Center, Department of Rehabilitation Medicine
750 Washington St., Boston, MA 02111

Bruce M. Gans, M.D., Chm. Rehabilitation Medicine

Page

Medication Effects on Attention and Arousal (with the **National Institute on Disability and Rehabilitation Research**) 342

United Cerebral Palsy Research Educational Foundation
66 East 34th St., New York, NY 10016

Leon Sternfeld, M.D., Medical Director

Page

Design of Instrumentation to Quantify Upper Extremity Motor Control of Children with Cerebral Palsy: Pilot Study . . . 282

U.S. Department of Education, Office of Special Education and Rehabilitation Services
NADIR, 3423/Switzer Bldg., 330 C St., S.W., Washington, D.C. 20202

Page

Application of Technology to Enhance the Employability of Severely Communicatively Impaired Individuals 196

Automatic Lens Focusing for the Visually Impaired (with the **National Institutes of Health**) 388

University of Akron
1621 Flickinger Rd., Akron, OH 44312

Page

Mechanics of Ankle Foot Orthoses 61

University of Michigan, Rehabilitation Engineering Program, Department of Physical Medicine and Rehabilitation
Ann Arbor, MI 48109

Page

A Computer Interface for the TIPE Seating Pressure Evaluator 98

ALTKEY: A Multi-Mode Input Program for the IBM-PC 192

Electrically Controlled Talking Tracheostomy Systems . . . 423

University of Salford Venture and Enterprise Fund
University of Salford, Salford M5 4WT, United Kingdom

Page

Development of a Motorized, Adjustable Standing Frame 142

University of Texas Medical Branch, 301 University Blvd., Galveston, TX 77550
George T. Bryan, M.D., Director

Page

Reorganization of Brain Function in Recovery from Aphasia (with the **U.S. Department of Education**) 435

University of Toronto
Toronto, Ontario, M5S 1A1, Canada

Page

A Model for the Assessment of the Written Communication of Nonspeaking Physically Disabled Individuals Who Use Microcomputers (**Speech Pathology Alumni Association** with the **Hugh MacMillan Medical Centre, Research Department**) 197

Feasibility Assessment of a FNS Hand Orthosis for Quadriplegics (**Department of Rehabilitation Medicine** with the **Canadian Paraplegic Association**) 222

Variety Club of Ontario, Tent #28
Loews Westbury Hotel, Suite 1721, 475 Yonge St., Toronto, Ontario M4Y 1X7, Canada

Page

Powered Upper Extremity Prosthetics Research and Development Project: Development of Child-Sized Electromechanical Hands 43

Powered Upper Extremity Prosthetics Research and Development Project: Development of a Child-Size Electromechanical Elbow 51

Development of a Protective Foot and Leg Guard for Use in Wheelchair Sports 142

Development of A Wheelchair-Accessible Weight Training Gym 170

Whitaker Foundation
Whitaker College of Health Sciences, M.I.T., 77 Massachusetts Ave., E25-526, Cambridge, MA 02139

Page

Properties and Control of Stimulated Muscles 219

Hybrid Brace for Paraplegic Gait Restoration 237

Women's Royal Voluntary Service
Princess Margaret Rose Orthopaedic Hospital, Edinburgh EH10 7ET, Scotland

Page

Research Into the Use of a Shape Memory Alloy as a Power Assistive Component for Upper Limb Prostheses 41

Section III.

FUNDING ORGANIZATIONS

This section is intended to assist rehabilitation researchers in the identification of potential sources of funds available for rehabilitation research and development projects. Such information, in addition to generally aiding research progress, is intended to encourage researchers to find private sources of funds, to extend and amplify funds provided by the VA and other government agencies.

The information presented here was obtained by a mail survey of all agencies listed as research sponsors in Section II of this report.

Unfortunately, most of the respondents are government agencies, but the information is still judged to be useful. Efforts will continue in future editions of *Rehabilitation R&D Progress Reports* to expand coverage of funds available from the private sector.

AMERICAN FOUNDATION FOR THE BLIND

15 West 16th Street
New York, NY 10011
(212) 620-2140

National clearinghouse for local agencies serving the blind.
Serves as research, consultative and informational agency for blindness.

Contact person: Corinne Kirchner

Number of projects related to rehabilitation in 1987: 2

Purpose of grants: To encourage research attention to psychosocial aspects of blindness and low vision.

Research areas of interest: Social science topics in relation to blindness and low vision.

Eligibility requirements: Project approved for doctoral dissertation research at an accredited university.

Application procedures:

deadline: early January and early April each year; specific dates announced annually

duration: one year with extensions if prior approval obtained

Send for packet.

AMERICAN OCCUPATIONAL THERAPY FOUNDATION

1383 Piccard Drive
Rockville, MD 20850
(301) 948-9626

The American Occupational Therapy Association (AOTA) is a professional organization of occupational therapists which conducts research programs and compiles statistics pertaining to occupational therapy.

Contact person: Nedra Gillette

Number of projects related to rehabilitation in 1987: 5-10

Purpose of grants: To build the knowledge base in occupational therapy.

Research areas of interest: Development of the science of occupations and the application of occupational therapy. Special interest currently in the development of good research instruments.

Eligibility requirements: Member AOTA

Application procedures:

deadline: quarterly: December 15, March 15, June 15, September 15

duration: 12 months

Send for packet.

EASTER SEAL FOUNDATION

2023 W. Ogden Ave.
Chicago, IL 60612
(312) 243-8400

The Easter Seal Research Foundation is part of the National Easter Seal Society and administers grants-in-aid for research concerned with physical disabilities.

Contact person: Rita McGaughey, Associate Director

Number of projects related to rehabilitation in 1987: 8

Purpose of grants: To investigate rehabilitation methods that can enhance existing and stimulate new services provided by Easter Seal Societies for promoting independent living for persons with disabilities.

Research areas of interest: Development, refinement or adaptation of technologies to assess, treat or manage disabilities and promote independent living for persons with disabilities.

Eligibility requirements: Universities, medical centers, organizations with appropriate qualified staff.

Application procedures:

deadline: March 1, August 1 in 1988 and January 15, 1989

duration: 3 years (beginning in 1989, 2 years)

Send for packet.

EASTERN PARALYZED VETERANS ASSOCIATION

432 Park Avenue South
New York, NY 10016
(212) 686-6770

The Eastern Paralyzed Veterans Association is a chapter of the Paralyzed Veterans of America (PVA) whose goal is to help better the lives of disabled veterans. This organization has 200 members in New York, New Jersey, Pennsylvania and Connecticut.

Contact person: Vivian Beyda, Ph.D.

Number of projects related to rehabilitation in 1987: 6

Purpose of grants: To further research in the area of spinal cord injury.

Research areas of interest: Spinal cord injury.

Eligibility requirements: Proposals are submitted to the Spinal Cord Research Foundation for review.

Application procedures:

deadline: January 1 and July 1

duration: 12 months with up to 2 renewals

Send for packet.

NATIONAL CANCER INSTITUTE

Division of Cancer Prevention and Control
Community Oncology and Rehabilitation Branch
9000 Rockville Pike
Bethesda, MD 20892-4200
(301) 427-8708

The goal of the National Cancer Institute is to find the cause and prevention of cancer as well as the treatment and rehabilitation of cancer patients.

Contact person: Carolyn Cook Gotay, Ph.D., Program Director for Rehabilitation and Continuing Care

Number of projects related to rehabilitation in 1987: 15

Purpose of grants: To support the National Cancer Institute's cancer control mission—to reduce incidence, mortality, and morbidity due to cancer.

Research areas of interest: Rehabilitation research that aims to reduce cancer morbidity in the areas of physical, psychological, social, and vocational functioning.

Application procedures:

deadline: three competitions a year (dates vary according to type of grant)

duration: up to five years

Send for packet.

NATIONAL EYE INSTITUTE

Bldg. 31, Room 6A27
9000 Rockville Pike
Bethesda, MD 20892
(301) 496-4308

The National Eye Institute conducts and supports research in the causes, prevention and treatment of visual disorders.

Contact person: Constance Atwell, Ph.D.

Purpose of grants: To advance research designed to enhance

the rehabilitation, training and quality of life of blind and partially sighted persons.

Research areas of interest: Low vision.

Eligibility requirements: Researchers, agencies and small businesses may be eligible.

Application procedures:

deadline: Jan 10, May 10, Sept 10 for all institutional National Research Service Awards. Feb 1, June 1, Oct 1 for all new grant and research career development awards.

Send for packet.

NATIONAL INSTITUTE ON DISABILITY AND REHABILITATION RESEARCH

Room 3060, 330 C Street, SW
Washington, DC 20202
(202) 732-1134

The National Institute on Disability and Rehabilitation Research (NIDRR) (formerly the National Institute of Handicapped Research) is an agency of the Department of Education whose mission is to carry out a variety of activities and research related to disability and rehabilitation.

Contact person: Richard LeClair, Acting Director

Number of projects related to rehabilitation in 1987: 44

Purpose of grants: Planning and conducting research and demonstration projects in areas that have a direct bearing on the development of methods, procedures, and devices to assist in the provision of rehabilitation services to disabled individuals.

Research areas of interest: Scientific, technical, methodological and other investigations into the nature of disability.

Methods of analyzing disability, and techniques for rehabilitation, including basic research where related to rehabilitation techniques or services.

Eligibility requirements: Public and private organizations including profit and not-for-profit.

Application procedures:

deadline: September, March (exact dates vary yearly)

duration: 3 years

Send for packet.

NATIONAL INSTITUTE OF NEUROLOGICAL AND COMMUNICATIVE DISORDERS AND STROKE

9000 Rockville Pike
Bethesda, MD 20892
(301) 496-4188

This Institute conducts and sponsors fundamental and applied research on human neurological and communicative disorders and the development and function of the brain and nervous system.

Contact person: Edward M. Donohue

Number of projects related to rehabilitation in 1987: 19

Purpose of grants: To support rehabilitation research related to neurological and communicative disorders and stroke.

Research areas of interest: Rehabilitation research related to neurological and communicative disorders and stroke.

Eligibility requirements: Non-profit and for profit organizations.

Application procedures:

deadline: Feb 1, June 1, Oct 1 annually for research project applications and April 15, August 15, and December 15 annually for SBIR applications

duration: up to 5 years

Send for packet.

NATIONAL SPINAL CORD INJURY ASSOCIATION

600 W. Cummings Park

Woburn, MA 01801

(617) 935-2722

The National Spinal Cord Injury Association is involved in assistance to individuals, education of the public and research relevant to spinal cord injury.

Contact person: Jonathan Spack

Number of projects related to rehabilitation in 1987: 1

Purpose of grants: To further research in the field of spinal cord injury.

Research areas of interest: Central nervous system regeneration.

Eligibility requirements: Policies under revision.

Application procedures: Policies under revision.

NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL OF CANADA

200 Kent Street

Ottawa, Canada K1A 1H5

(613) 995-5997

The Natural Sciences and Engineering Research Council is Canada's largest research granting agency. While it does not target any of its research directly in the area of rehabilitation, it does fund university professors and students to conduct both basic and applied research that is of interest to handicapped persons and rehabilitation workers. This research includes medically-related biochemistry and physiology, genetics, epidemiology and drug addiction. The Council also funds research into the engineering of prosthetic devices and artificial limbs as well as research in computing, communications and instrumentation technology.

Contact person: Arnet Sheppard, Public Affairs Officer

Purpose of grants: Varies with grant.

Research areas of interest: General research as well as research into natural sciences and engineering; grants in biotechnology, communication and computers, environmental toxicology, industrial materials and processes and open (other research).

Eligibility requirements: Applicant must be an academic staff member of an eligible Canadian University.

Application procedures:

deadline: various

duration: 1 to 3 years

Send for packet.

PARALYZED VETERANS OF AMERICA SPINAL CORD RESEARCH FOUNDATION

801 18th Street, N.W.

Washington, D.C. 20006

(202) 872-1300

The PVA sponsors research, rehabilitation and education related to paralysis of veterans. It also assists paralyzed veterans improve the quality of their lives through employment, benefits, and recreational activities. The PVA promotes legislation, employment and housing for paralyzed veterans.

Contact person: Priscilla A. Craig

Number of projects related to rehabilitation in 1987: 20

Purpose of grants: To encourage research in the field of spinal cord research.

Research areas of interest: Basic science, biomedical, technological, design development, psychosocial, research fellowships, with relevance to spinal cord injury/dysfunction.

Eligibility requirements: Anyone interested.

Application procedures:

deadline: January 1, July 1

duration: up to 3 years, renewable each year with new application and good progress

Send for packet.

VAUGHAN CHAPTER, PARALYZED VETERANS OF AMERICA

PO Box 1337

Hines, IL 60141

(312) 344-8214

The Vaughan Chapter PVA is located at the Hines Veterans Administration Medical Center in Illinois and is one of the 40 local PVA chapters across the US. It assists paralyzed veterans and sponsors research in spinal cord injury and diseases.

Contact Person: Shirley Rohwedder

Number of projects related to rehabilitation in 1987: 3

Purpose of grants: To carry on research.

Research areas of interest: Electrical stimulation. Development of a wheelchair wind resistance aerobic fitness trainer—and neuroscience and regeneration research at Yale University.

Eligibility requirements: Spinal cord injury and/or spinal cord disease related research.

Application procedures:

deadline: August 1

duration: 1 year

Send for packet.

VETERANS ADMINISTRATION REHABILITATION RESEARCH AND DEVELOPMENT SERVICE

810 Vermont Avenue, N.W.
Washington, DC 20420
(202) 233-5177 or (202) 233-5179

The mission of the Rehabilitation Research and Development Program is to improve the quality of life for impaired, disabled, and handicapped veterans by making them more functionally independent.

Contact person: Office of the ACOS R&D at the local VA Medical Facility.

Number of projects related to rehabilitation in 1987: 115

Purpose of grants: Research, development or evaluation in the field of rehabilitation.

Research areas of interest: Sensory aids, spinal cord injury, prosthetics/amputation and gerontology.

Eligibility requirements: Staff of VA health care facilities, qualified researchers from affiliated medical, dental and engineering schools and certain rehabilitative engineering directed businesses.

Application procedures:

deadline: research or development proposals—April 15 and October 15; request for evaluation at any time; pilot proposals at any time

duration: 3 years

Send for packet.

Section IV

Subject Index

A

Acceptance of Disability (AD) scale 206-207
 Action potential
 compound (CAP) 309
 motor unit (MUAP) 295-296, 299, 301
 single fiber (SFAP) 309
 Activities of Daily Living (ADL) 188, 221-223, 250, 315, 341
 Aggressive nutritional intervention (ANI) 89-90
 Agraphia 420
 Alexia 420
 Alzheimer's disease 344, 350, 362
 American Sign Language (ASL) 423, 439
 Anemia 108-109
 Ankle foot orthosis (AFO) 8, 57, 60-62, 135, 277
 Antibiotics 112, 115-116
 Arthritis Center
 Multipurpose (MAC) 317-318, 321-323
 Stanford (SAC) 319-320
 Arthritis Impact Measurement Scale (AIMS) 162, 324
 Assistive Device Assessment Program (ADAP) 196-197
 Assistive listening systems (ALS) 413
 Atherosclerotic occlusive disease (ASOD) 328-330
 Audio-visual laser videodisc interactive system (ALVIS) 404-405
 Auditory/Karhunen-Loeve (AKL) 414
 Autonomic dysreflexia 96-97, 104-105, 118-119
 Autonomous Functioning Checklist (AFC) 204-205

B

Back-scattered electron imaging (BEI) 76, 80
 Blood rheology 1-2, 25, 85, 105-106
 Bone mineral content (BMC) 260-261
 Boston Elbow 47
 Bus aides 169-170

C

CAD/CAM 6-7, 20-22, 35, 38, 80, 153, 264, 291
 CAT-CAM 30
 CODA-3 21, 23, 87
 COGORTH 167, 195
 Calcium
 metabolism 65, 69, 108
 salts 108, 285
 Carbon Copy Foot 18
 Carbon fiber reinforced plastic (C-FRP) 60
 Card Sort Procedure (CSP) 203-204
 Cardiac output 230-231
 Central nervous system (CNS) 120-122, 125-126
 Cerebral palsy 146, 149, 151, 153, 168, 194, 254, 279-282, 313, 447-450
 Chemical dependence 99
 Chronic obstructive pulmonary disease 442
 Closed head injury (CHI) 91-94

CoCr implants 69-70, 77

Comprehensive renal scintigraphy procedure (CRSP) 113
 Computer-Aided Visual Communication (C-VIC) 429-430
 Computer-Assisted Driver Assessment System (CADAS) 245-246
 Computer-aided surgical stimulation (CASS) 263-265
 Computer-assisted interactive video (CAIV) 404-405
 Computerized axial tomography (CAT/CT) 20, 22, 69, 96, 210, 240, 255-256, 259-260, 265, 286, 314, 341
 Connected Speech Test (CST) 419-420
 Contrast Sensitivity Functions (CSF) 368
 Cross-modality matching (CMM) 401-402
 Cyclobenzaprine 4

D

DECTalk Speech Synthesizer 366, 437-438
 DataGlove 56
 Decubitus ulcers 83, 85, 98, 102-104, 106, 148-149, 287
 Delayed hypersensitivity 89
 Dementia 362
 Dexter (robotic hand) 375-376, 386
 Diabetics 8-9, 12, 14, 26, 53-56, 289-290
 Diazepam 113
 Diffusional conductance 1-2
 Direct current stimulation 229
 Disability units
 ablution 154-155, 158-159, 161, 165-166
 home 161-162, 166
 Disintegration
 carpal (CD) 292-293
 tarsal (TD) 15-16, 292-294
 Dotless braille 385-386
 Down's syndrome 251
 Dye fluorescence index (DFI) 25
 Dynamic elastic response (DER) 17-18
 Dysphagia 335-336

E

Electrical muscle stimulation (EMS) 83-84, 86, 210-213, 237
 Electrocardiogram (ECG) 133, 168, 239, 243, 341, 351
 Electromagnetic stimulation 229-230
 Electromyogram (EMG) 17, 29, 32-33, 39, 48, 55, 74, 81, 84-85, 106, 127-128, 168, 209, 214, 217, 219, 221, 233-234, 242, 258, 262, 264, 269, 278-279, 282, 295-296, 325, 344, 346, 448, 450
 Electronic Travel Aides (ETA) 389
 Electroretinogram (ERG) 363, 387, 403-404
 Electrostimulation (seminal emission) 128, 215
 Employee Assistance Program (EAP) 157-158
 Excretory urogram (EXU) 113
 Extended physiological proprioception (EPP) 39, 44-46, 48-49, 51, 148

F

Family Asthma Rehabilitation Program (FARP) 450, 457
 Finite impulse response (FIR) 400
 Fixed Ankle Brace (FAB) 16
 Flex foot 18
 Fluorescein 3, 5
 Functional Independence Measure (FIM) 247-248
 Functional electrical stimulation (FES) 102, 209-210, 230-231, 234-235, 291-292
 Functional neuromuscular stimulation (FNS) 15, 87, 95, 106-107, 115, 117-118, 218, 220-225, 227-228, 231-234, 236, 311

G

Goniometry 55
 Graded weight-bearing (GWB) 293-294
 Gunshot wounds 89, 109-110

H

H-reflex 84-85, 336 341
 Handbike 155
 Hearing performance inventory (HPI) 405
 Helium flux 1-2
 Heterotopic ossification (HO) 110-111
 Hip Guidance Orthosis (HGO) 58-59
 Horseradish peroxidase (HRP) 122-123, 126
 Hosmer NYU elbow 44
 Human leucocyte antigen (HLA) 112-113
 Hydroxyapatite (HA) 285

I

ISNY 24-25
 Infant crib 167
 Intermittent catheterization program (ICP) 108
 Issues in Disability Scale (IDS) 207-208

J

JHU/APL arm 171-172

K

KIOSK software 437-438
 Kevlar-reinforced epoxy 37

L

LSU orthosis 235
 Laminectomy 107
 Large print displays (LPD) 395-396
 Laryngograph 444
 Laser Doppler instrumentation 1-2, 25, 85, 237, 288, 327-328, 341, 345
 Leprosy 15-16, 280-281, 292-294, 311-313
 Ligament
 anterior cruciate (ACL) 58, 258, 261-263, 307-308
 medial collateral (MCL) 307-308
 Light-emitting diodes (LED) 268, 271

M

Magnetic resonance imaging (MRI) 140-141, 265
 Magnitude

absolute magnitude estimation (AME) 401-402
 absolute magnitude production (AMP) 401-402

Metatarsalgia 57

Microscopy

 electron 66, 68, 96, 119, 122, 126, 128, 211, 289
 light 96, 126, 128

Minimum audible pressure (MAP) 406

Mobile Assessment Laboratory (MAL) 244-245

Modulation transfer function (MTF) 377

Mouthstick 160, 189

Mueller cells 403-404

Multiple Family Discussion Group (MFDG) program 205-206

Muscle fatigue monitor (MFM) 305

Muscular dystrophy 59-60

N

Neofrakt stockinette 57
 Nerve growth factor (NGF) 123-124
 Neurochemicals 96-97
 Neuropathic ulceration 8, 53
 Nifedipine 4
 Nitinol 369

O

Occupational Therapy Comprehensive Functional Assessment (OTCFA) 199

P

PMMA bone cement 64-65, 67
 PPT 14
 Pacinian corpuscle 350
 Parathyroid hormone (PTH) 70
 Patellar tendon bearing (PTB) prosthesis 28
 Pelite 14
 Personal Independence Profile (PIP) 162-163
 Perthes disease 62
 Phantom pain 4, 11-12
 Physiological Cost Index (PCI) 59, 239-240
 Plastazote 14
 Porch Index of Communicative Ability (PICA) 432
 Portable anticipatory communication aid (PACA) 188-189
 Present Pain Intensity (PPI) 251-252
 Profile of Mood States (POMS) 365-366

Q

Quantitative perfusion fluorometry (QPF) 3-5, 10-11, 25

R

Reciprocating Gait Orthosis (RGO) 58-59, 239-240
 Recommended Daily Allowance (RDA) 90
 Red blood cell (RBC) 108-109
 Response Elaboration Training (RET) 428
 Room temperature vulcanizing (RTV) silicones 39

S

SACH foot 8, 14, 17-18, 29
 SAFE foot 8
 SEATTLE foot 8, 18-19
 Selective posterior lumbar rhizotomy (SPLR) 447-448

Sensorineural hearing loss (SNHL) 410-411

Shape memory alloy (SMA) 41-43

Silicon avalanche detectors (SAD) 10

Simian aides 156

Small-Scale Vehicle (SSV) 246-247

Sorbothane 14

Sound pressure level (SPL) 406-407

Spenco 14

Stenfoot 18

Stratum corneum 1-2

Supportive Work Employment Project (SWEP) 156-157

Surface replacement hip arthroplasty (SRHA) 75-76

Symptomatic Glottic Insufficiency 441

Systemic lupus erythematosus (SLE) 316-317, 319

T

TEL-Communicology (TEL-C) 432-433

TRACK software system 73, 264-265, 268, 271

Talking Tracks 397

Texas Interface Pressure Evaluator (TIPE) pad 98

Thallium scintigraphy 10

Ti-6Al-4V alloy 66-67, 72

Trans Pennine Splint (TPS) 62

U

UNISTIK 144

Ultrasonic Head Control Interface (UHCI) 144-145

Urinary

 incontinence 82-83, 106-107, 114, 346, 358

 tract complications 111-113

Usher's syndrome 379

Utah Arm 45

V

Visual Skills for Reading Test (VSRT) 397-398

Vocational Education Readiness Test (VERT) 381

W

Wheelchair Aerobic Fitness Trainer (WAFT) 139

X

Xenon washout 2, 5, 9-10, 83-84

Xylocaine 312

Z

Zimmer Harris/Galante Cup 68

Zyderm collagen 441

Section V. Author Index

- Abbs JH 438
Abbott GD 414
Abrahamson JE 404
Acierno M 59
Adams DJ 255
Adjouadi M 394
Adkisson J 375
Affleck GG 317
Agarwal GC 84
Agasid EF 34
Aguayo AJ 120
Ahlstrom CJ 405
Akabas S 157, 472
Albright JA 314, 331
Aldrich J 278
Alexander GC 419
Alexander J 137
Alexander MP 338
Alfred W 132
Allard P 14, 56, 269
Allen EJ 196
Amerson TL 395
Amster WW 432
Anderson LL 181
Anderson MJ 120
Anzel SH 16, 29, 270, 470
Apple DF 86
Arditi A 377
Arena JG 326
Arenberg D 349
Armstrong TR 445
Aten JL 443
Au-Yeung H 397
Axelson P 155
Ayyappa E 16, 17, 18, 29
Ayyar DR, 209
- Bablich K 282
Bach-y-Rita P 12
Bachus KN 75
Baer DC 48
Bagley S 347
Bahrani AS 6
Bailey IL 368
Bails JH 158
- Baird R 29
Baker E 338
Bakshi KR 10
Bar-Ner M 119
Baranowski TJ 229
Barja R 11, 326
Baron-Robbins A 166
Barris R 199
Batavia AI 451
Baumgardner JE 1, 2
Beaupré GS 78, 283
Beck LB 399
Beck P 349
Becker JC 42
Belhobek GH 151
Bellugi U 423
Benjuya N 127
Benko H 291
Bennett L 148
Bennett RM 317
Berg EW 54, 63, 255, 256
Berger N 24
Berkowitz M 159
Bermudez M 304
Bernauer E 243
Berndt RS 434
Bernstein L 414
Bess JC 432
Bigos SJ 249
Binder LM 339
Black PM 350
Blackwell G 201
Blake DJ 317
Blasch B 389
Blazey M 441
Bloch E 470, 478
Bobbert MF 299
Bochmann D 449
Bolam J 106, 212
Boone DA 6, 7
Boothroyd A 416
Borden PA 452
Borthwick B 185
Boscardin J 262
Bostrom JA 154
- Bourgeois M 427
Bowker P 58, 142, 239, 253, 269
Bowles J 185
Brabyn J 383, 480
Braddock D 459
Bradshaw AJ 160
Brandenburg SA 452
Bray GM 120
Brenchley C 222
Bresler MI 30
Brickman E 157
Brighton CT 292
Britell CW 144
Brodin G 480
Brodsky J 14
Brogdon JL 350
Brousseau DA 3, 5
Brown R 60
Brubaker CE 140, 153
Bruce J 479
Brucker BS 209
Brunner C 315
Bruno GM 11, 326
Brunski J 63
Bryan GT 481
Bubien JK 113
Bucholz RW 286
Buckett JR 220, 223
Bugaresti J 186, 222
Bull B 411
Bullis M 411
Bunch KS 166
Burgess EM 6, 7, 19, 288, 289, 290
Burns JR 108
Burns SD 30
Burrow M 160
Bush TL 351
Buskey JM 165
Byers-Hinkley K 60, 254
- Calhoun SA 396
Cameron W 179
Campbell V 396
Campos RJ 115

- Canilang EP 335
Cannon WD 259
Cardus D 133
Carlson GS 429
Carlson LE 45
Carmichael T 325
Carter DR 71, 78, 283
Carter RE 101
Casavant D 297, 303
Casterline J 335
Cavanagh PR 53
Celli BR 304
Cerullo L 37
Chambers R 17, 18
Chang RW 324
Chao EY 266
Chemtob CM 440
Chen CS 380
Chen S 381
Chen TC 456
Childress DS 20, 21, 22, 36, 38, 42, 44, 46, 86, 188
Chinoy MJ 212
Chizeck HJ 15, 131, 231, 232
Chua Y 457
Church D 472
Ciccone C 254
Clark MB 121
Claus-Walker J 116
Cline JE 251
Cochran GVB 63, 102, 104, 284
Coen M 29
Cohen C 75
Collins M 422
Condon SM 277
Congleton JJ 138
Convery FR 64
Cook SD 65, 66, 67, 69, 72
Cooke FW 63
Coombs FK 464
Cooper WA 405, 406
Copenhaver R 447
Cordo PJ 48
Costanzo DM 251
Courington S 390
Cox R 419
Crago PE 15, 131, 236
Craig JC 382
Crangle C 171
Crimmins EM 351
Csongradi J 283
Cuckler J 75
D'Ambrosia R 58, 80, 263, 268
Daly JM 5
Damond M 204
Daniels AU 75
Darcy K 332
D'Astice 106
Davey K 363
Davidoff G 94
Davis GM 230
De l'Aune WR 389, 397
DeLateur BJ 277
DeLuca CJ 240, 272, 297, 299, 300, 301, 302, 303, 305, 336, 341, 473, 478
DeTorie N 255, 256
DeVivo MJ 87
Deal JL 446
Dean D 159
Demarsh J 453
Deutsch G 435
Devellis B 318
Deveney CW 5
Devine SA 452
Dick TD 38, 236, 273
Dickerson A 472
Dimitrijevic MR 115
Doktycz H 106
Donath M 274
Donovan A 362
Donovan DM 255
Donovan WH 101
Dooley RL 442, 458
Dorfman LJ 295, 296
Douglas R 57, 235
Doyle PJ 427
Draper ERC 168, 291
Dronkers NF 446
Drouin G 14
Ducheyne P 75
Duhaime M 269
Dunlop RJ 404
Dunn M 238
Durfee WK 131, 219, 237
Durlach NI 415
Dyer AR 324
Dzenowagis J 274
Easton R 369
Eckman T 201
Edgerton RB 352
Edmond P 236
Edwards LA 454
Eisenberg HM 435
Eldridge N 447
Elliot P 80
Elliott DC 421
Elston R 380
Emley M 297
Engebretson AM 399
Engel BT 352
Engvall E 119
Entrikin RK 242, 244
Erb RA 37
Ernst JL 11
Esquenazi A 27
Evans CH 70
Evans DA 352
Ezenwa B 230
Falconer J 324
Fallen J 236
Fant G 425
Fausti SA 346
Fay L 43
Feinstein C 204
Feldman S 115
Festervand T 166
Figoni SF 230
Finnerty-Fried P 207
Fisher L 289
Fisher W 390
Fisher WE 143, 149
Fishman S 24
Fitch S 362
Fitzgerald D 473
Flevaris-Phillips C 408
Flowers W 275
Ford CN 344, 441
Ford MC 362
Forsgren SM 6, 7
Fowler WM 243, 244
Fox JC 362
France J 238
Freeburg J 411
Freed MM 88
Freehafer AA 92
Fries JF 319
Frymoyer JW 326
Fu C 180
Fuhrer M 101
Fujiura G 459
Fyhrie D 71
Gaines T 472
Galante SR 2
Galway R 43, 51
Gambert SR 353
Gamradt JE 452
Gans B 481

- Garbarini MA 31
 Garber S 134
 Garbini JL 79
 Garrett RE 143, 183, 198
 Geers A 416
 Geggie CG 183
 Gehlsen GM 353
 Gelfand SA 401
 Gerfen D 114
 Geruschat DR 389
 Giannini MJ 347, 461
 Gibbons DT 51
 Giddens DP 327
 Giesen JM 373
 Gilbert DJ 432
 Gilden D 375, 383
 Gilliss CL 354
 Gilmartin D 156
 Gilmore C 419
 Gilmore LD 240, 297, 298, 303, 305
 Gilpin AT 255, 256
 Ginige A 179
 Giyanani VL 314
 Glaser RM 230
 Glass D 209
 Glenn M 342
 Goeppinger J 315
 Goldberg G 474
 Golbranson FL 8
 Goldstein H 427
 Goldstein LP 441
 Goldstein MH 415
 Golper LA 339
 Gomez G 300
 Gonzalez S 205
 Goodenough-Trepagnier C 337, 338, 373
 Goodrich GL 238, 392
 Gordon WA 339
 Goshgarian HG 122
 Gottlieb G 84
 Gottschalk F 13, 14
 Goudreau L 169, 177
 Gouvier WD 246
 Gow D 38, 39, 41
 Gown A 289
 Graboys T 316
 Graf PM 55
 Grafstein B 125
 Grahm EC 38, 42, 45, 46
 Gramming P 425, 426
 Gramata J 391
 Granger CV 247
 Granström B 425
 Gratzner M 212
 Graves DJ 1, 2
 Graves WH 374, 375, 380, 474
 Green BA 209
 Greenhalgh R 382
 Greenlee TK 79, 288
 Gregorio T 134
 Griffith JD 347
 Gross A 273
 Gross MD 83
 Gruner JA 233
 Gupta SC 230
 Habeck RV 455
 Haber L 391
 Haber R 391
 Haddad RJ 67
 Hale PN 244, 245, 246
 Halstead L 115
 Hambley J 457, 458
 Hamilton BB 247
 Hammel J 173, 174
 Hanks D 159
 Hanno MH 272
 Hansen JA 165
 Harkins JE 412
 Harrington I 273
 Harrington RM 288
 Harris JM 73
 Harris RM 118, 123
 Harte TJC 280
 Hartridge M 146
 Harwin WS 179
 Haucke M 378, 381
 Hayes WC 267
 Healy B 472
 Heckathorne CW 38, 44, 46, 188
 Heinemann AW 99
 Hellman RP 401, 402
 Hemp R 459
 Hennies D 392
 Henry RE 9
 Hentz VR 309
 Heppenstall BR 75
 Herbert M 213, 222
 Heslinga H 299
 Hight T 278
 Hillstrom H 32
 Hinckley JA 471
 Hizer J 442
 Hoffer JA 218
 Hofmann AA 75
 Hogan N 46, 49
 Holewski JJ 8
 Hollis L 278
 Hollyfield R 367, 390, 391
 Holman HR 319
 Holmok CL 209
 Houston VL 31, 345
 Howard JE 295, 296
 Huang CT 89, 108
 Hudson LM 86
 Huijing PA 299
 Hulsebosch CE 123
 Humphreys PK 6
 Hussey RW 171
 Hutchins SE 340
 Huynh A 296
 Hwang MH 139
 Hyman WA 168
 Ignagni A 224
 Jabre JF 303
 Jackson R 378
 Jackson RD 179
 Jaffe DL 144, 365, 375, 437
 Jakubson M 281
 James WV 6, 59, 277, 280
 Jampolsky A 383, 480
 Jaros LA 98, 166, 192, 195
 Jarvis S 147, 185, 193, 313
 Jensema CJ 412
 Johnson AD 369
 Johnson DE 82
 Johnson E 189
 Johnson KD 285
 Johnson KO 457
 Johnson MW 95
 Jones RE 286
 Jones WL 354
 Juni JE 83
 Kadaba MP 104, 284
 Kalata P 388
 Kalderon N 124
 Kalstein RI 337
 Kamen G 302
 Kaplan H 399
 Karam F 436
 Katz M 377
 Kayser-Jones VS 355
 Kearns KP 428, 432
 Keith MW 92, 102, 215, 221, 224, 226, 227, 228
 Kelford S 197
 Keller TS 260
 Kelly G 395

- Kelso DP 190, 191
Kenna R 262
Kenney SB 127
Kenny D 449
Kent H 470
Kester MA 69
Kett NA 210, 212
Kett RL 83, 98, 423
Keyak JH 259
Khan T 106, 107, 117
Kilgore K 228
Kim D 5
Kim M 5
Kimbrough E 442
King A 235
Kirchner C 374
Kirchner JC 408
Kirsch NL 166, 195
Kirschner GB 238
Kleczewska MK 429
Klein SG 3
Knaflitz M 219, 306
Knight RT 446
Ko W 231
Kobetic R 231, 232
Koblasz A 363, 403
Koester DJ 423
Koheil R 282, 448, 473
Kolenc A 291
Kondraske GV 325
Kopra LL 404
Kopra MA 404
Kourosh S 13, 14
Krauskopf M 157
Krauss M 355
Krebs DE 24
Krebs M 138
Krick H 38, 44, 45, 46
Krouskop TA 35
Kufper C 475
Kulkarni VN 15, 280, 292, 293, 311, 312
Kulp CS 315
Kung KS 287
Kurtz I 52
Kutner NG 356
Kwee HH 178
Kynast L 139

Labelle H 14, 56, 269
Ladin Z 59, 256, 271, 272
Lam PC 61
Lamb AM 379
Lang SM 256

Langbein WE 139
Lanno R 193
Larrivee DC 125
Larson RV 79
Larson VD 405, 406
Lawrence KL 286
Layeux G 167, 169
Leanderson R 425
LeBlanc M 40
Leclair RR 475
Leclerc L 56
Leder SB 408
Lee BY 148, 328, 330, 332
Lee CC 190, 191, 422
Lee J 278
Lee TQ 16, 17, 18, 29, 270
Lees D 173, 174
Legge GE 370
Lehmann JF 277
Lehmann K 104
Lehmkuhl LD 135
Lehneis HR 31, 345
Leibowitz LJ 44, 188
Leifer LJ 155, 171, 173, 174, 175, 464
Lemons JE 257
Letchipia J 102
Leventhal H 357
Levin HS 435
Levine C 391
Levine S 373
Levine SP 83, 98, 166, 192, 195, 423
Levison H 450
Levitt H 416
Lewis A 377
Liang MH 316
Liberman RP 201
Lieber RL 211, 217
Lieberman JS 244
Liggins AB 142, 253
Light RW 436, 443
Limbird T 55, 258
Lin Q 425
Linkowski DC 206
Linn MW 443
Linskell JR 168
Lipton JP 320
Little JW 118, 123
Liuzzi FJ 125
Lloyd LK 90, 215
Logan L 60, 254, 281
Long J 261
Loomis JM 310, 370

Lorance RW 363
Lord J 243
Lorenz M 261
Loshin DS 357, 371
Lotto W 147, 151, 279
Loudon IR 148, 273
Loverso FL 334
Lyon JG 428

Machalow S 381
Mackenzie CA 337
Magnano S 152
Maiman D 117
Majumder RK 200
Makas E 207
Malassigne PM 154
Maležič M 291
Malone JM 9
Manheim LM 324
Mann RW 263, 267
Mansour J 231
Marmion SL 374, 378, 379, 380
Marshall D 310
Marsolais EB 231, 232
Martin D 278
Martin R 472
Mason CP 233
Matsen FA 6, 7, 79, 288, 290
Maxson BJ 375, 379
Maxson JH 380
May-Gross B 348
Mayer NH 337
Mayer TG 325
McBroom LW 378, 380, 381
McCaa C 375
McCann K 421
McClenaghan B 282, 448
McCoy C 337
McGarr NM 416
McGill KC 295, 296, 309
McGovern T 150, 151, 152, 240
McIlhagger R 280
McKinley J 392
McLaughlin DE 200
McNaughton S 398
McNeal LW 395
McTaggart WG 133
Meadows CB 273
Meagher JM 259
Mears DC 70
Meenan RF 321
Mehta JM 15, 280, 292, 293, 311, 312, 479
Mekkittikul A 189

- Mendelson LS 92
 Menter RR 98
 Merletti R 219, 300, 306
 Merrit G 397
 Messenger N 58, 239, 253, 269
 Michalowski SJ 171, 175
 Micheo W 27
 Milhous RL 326
 Miller GE 168, 481
 Miller GJ 76
 Miller LJ 227
 Miller R 278
 Milne N 10
 Milner M 43, 51, 146, 151, 185, 213, 273, 279, 449, 450
 Milner P 408
 Minneman SL 181
 Mitchell K 348
 Mitteness LS 358
 Miyamoto H 60, 271
 Moghaddam P 38
 Molinaro DA 200
 Moodie CM 39
 Mooney V 13, 14, 325
 Moore B 435
 Moores DF 416
 Moran R 449
 Moriarty JB 200
 Morley RE 399
 Morris MA 371
 Morris T 274
 Mortimer JT 231
 Mosely C 313
 Moskowitz GD 32
 Mote CD 34, 259
 Moyle DD 54, 255, 256
 Munrowd DC 455
 Murdock DK 139
 Murphy N 269
 Murray JL 38
 Murthy KR 256, 271
 Myklebust BM 343
 Myklebust JB 117
 Mylrea KC 9

 Nakles K 427
 Napychank E 210
 Nasca RJ 257
 Naumann S 142, 170, 185, 186, 222, 313
 Nazar E 75
 Neeman HJ 478
 Neeman M 251, 478
 Neeman RL 251

 Nelson K 374
 Nelson TO 340
 Nemchausky B 129, 130, 139, 210, 212
 Nepomuceno CS 91
 Neth D 150, 279
 Neufeld GR 1, 2, 3, 5, 10, 25
 Neuman MR 131, 225
 Newport EL 439
 Nisbet P 148
 Nochomovitz ML 211
 Noda Y 341
 Noh JJK 238
 Nosek MA 136, 161, 162, 163, 164
 Novack TA 91
 Nyhuis R 305

 O'Donnell PD 346
 O'Leary A 315
 O'Reilly JL 82
 O'Riain M 51, 167, 169, 177
 Oakley F 321
 Odell K 422
 Odland G 289
 Ogilvie C 58, 62, 239
 Olerud J 289, 290
 Oliveri ME 203
 Olsson CF 183
 Orr JF 6, 59, 277
 Orr T 71, 283
 Ortiz M 156
 Oster AM 426
 Ostrander LE 328, 332
 Ottenbacher K 199
 Overbury O 238
 Ozer M 129
 Ozley CF 432

 Palmieri V 284
 Pang D 270
 Papanicolaou AC 435
 Pape K 213
 Pappas NJ 255, 256
 Parnes P 182, 184, 185, 187, 188, 193, 398
 Patwardhan A 261, 262
 Pavlovic J 274
 Peckham PH 92, 95, 102, 131, 215, 220, 221, 223, 226, 227, 228
 Pecoraro RE 26, 289, 290
 Peli E 368
 Perakash A 105

 Perakash I 85, 105, 128, 173, 174, 175, 234
 Perkins WH 425, 426
 Perlman A 444
 Perlman SG 322
 Perry J 17, 18, 29
 Petty RW 76
 Pham T 181
 Piehl F 54
 Popelka GR 399
 Pope MH 326
 Portny SE 159
 Portwood M 243
 Posner JD 358
 Potechin G 428
 Potter J 13
 Powell RJ 479
 Prasad C 126
 Prescott TE 334
 Price MB 12
 Price R 277
 Priemer R 393
 Pubols BH 311
 Pusakulich KM 419

 Quan-Hyatt M 447
 Quesada PM 26
 Quinn JA 1, 2
 Quinn K 39

 Rane MB 335
 Rappaport BZ 346
 Rappoport AF 6, 7
 Rassulo J 304
 Raubertas RF 416
 Raugi G 289
 Reddy NP 61, 335
 Reger J 342
 Reger SI 150, 151, 152, 240, 261, 279
 Reilly CA 1, 3, 5, 10, 25
 Reiss D, 203, 204, 205, 207
 Reynolds JC 255, 256
 Ribas-Cardus F 133
 Richard K 336
 Richards JS 93, 109
 Richardson F 408
 Riederer-Henderson MA 290
 Rinalducci EJ 361
 Rintala D 137
 Riso RR 131, 224
 Robb-Nicholson C 316
 Robbins V 381
 Roberson J 229

- Roberts AB 3, 10, 25
Robertson L 96
Robinette LN 392
Robinson CJ 84, 106, 107, 114, 139, 210, 212
Rodger RF 80
Rodgers BL 190
Rodgers MM 230
Rodriguez G 116
Roebroek ME 141
Rosati RJ 201
Rosen JM 310
Rosen MJ 248, 337
Rosenbaum P 241
Ross CK 324
Ross DA 395
Rossick C 413
Rothi LJG 420
Rouse DJ 347
Rovick JS 21
Rowell D 263
Rowley DI 58, 62, 239
Roy SH 240, 272, 303, 336
Rozendal RH 140, 141, 299
Rubel EW 409
Rubin G 31, 345
Rudd AK 432
Rudin NJ 240
Russo M 54
Ryals BM 409
- Sachdeva AK 3
Sacks AH 85, 105, 445
Saha S 314, 331
Sakurai Y 60
Salzman EW 332
Sanders LJ 53
Sane SB 15, 292, 293, 312
Sartori M 261, 262
Scala J 301
Scanio T 436
Schauer JM 190
Schild J 215
Schiller AL 80
Schloerb PR 96
Schmeisser G 176
Schmid FR 324
Schmidt D 209
Schrager R 80
Schurman D 71, 78
Schwab LO 165
Schwandt D 155, 278
Scott BL 417
Seaman J 380, 381
- Seaman RL 244, 245, 246
Seamone W 176
Seeger BR 143, 146, 149, 158, 161, 183
Seil FJ 127
Seliktar R 28, 48
Sendelbaugh J 411
Servedio FJ 230
Shalit A 347
Sharangpani RC 15, 280, 292, 293
Sharkey PC 115
Sharma S 222
Shea A 251
Shenaut GK 446
Sherman RA 4, 11, 326
Sherr E 59
Sherrick CE 417
Sherwood AM 115
Sheth PN 140
Shiavi R 55, 258
Shimazaki Y 60
Shindell SM 238
Shipp MK 246
Shoji H 235
Sibille J 169, 177
Sibley R 480
Sidles JA 6, 7, 79
Sigafos A 204, 207
Silverman DG 3, 5, 10, 25
Simmons BF 418
Simon SR 276
Simpson H 59
Sims DS 53
Singer W 342
Single T 160
Skinner HB 26, 34, 259
Smith B 226
Smith C 57
Smith DG 396
Smith G 375
Smith R 189
Smith RO 199
Smith TWD 62
Sochaniwsky A 282
Solar S 302
Solomonow M 57, 58, 80, 214, 217, 218, 235, 263, 268, 298, 473
Sorensen L 359
Spector M 229
Spengler DM 260
Spitzer JB 365, 408
Stamp WG 153
- Starr S 413
Stashuk D 297, 298, 299, 300, 301, 302, 303
Staub J 147
Steege JW 22
Steele RD 392, 429, 431
Stefanovska A 291
Stein J 106
Steinglass P 205
Stern SL 452
Sternfeld L 481
Stess RM 55
Stewart TP 152
Stills M 13, 14
Stoddard SL 96
Stover SL 110, 111
Stragiotti L 479
Strauss A 55, 258
Strauss MG 286
Stroh KC 221
Stryzik JS 42, 44, 46
Subbarao JVS 210, 212
Sundberg J 425, 426
Sun S 34
Suppes P 171
Suryaprasad AG 230
Sutin JA 324
Swiontek T 117
Szeto AYJ 196
- Takacs H 375
Tannenbaum H 56
Taylor B 171
Taylor M 458
Taylor RG 243
Tepperman P 273
Ternström S 425, 426
Tervo R 313
Thakor NV 42
Thom AK 5
Thoma B 29
Thomas KA 67, 69
Thompson B 363
Thompson DJ 392
Thompson HE 314
Thrope GB 221
Thurston S 197
Tidwell AA 432
Till JA 436
Tillman HH 359
Timberlake GT 372
Tkacik M 255, 256
Tobin MJ 382
Tokimura K 60

- Torburn L 17, 18, 29
 Tractman LH 347
 Traub J 347
 Trimble J 129, 130, 364, 367, 391, 393, 397, 463
 Triolo RJ 32
 Trullinger RW 421
 Turk R 291
- Vachranukunkiet T 27, 28
 Valainis EV 295
 Valenzuela JA 418
 Van Vorhis RL 21, 86
 Van der Loos HFM 173, 174, 175
 Van Ingen Schenau GJ 299
 Vanderheiden GC 190, 191, 422, 452
 Van der Woude LHV 140, 141
 Vaughan CL 447, 458
 Vaughn GR 432
 Veeger HEJ 140
 Verrier M 222
 Verrillo RT 360
 Vervena L 261
 Vilanueva T 3
 Voda JA 188
 Vodovnik L 291
- Waites KB 112
 Waldron RL 255, 256
 Walker JH 257
 Walker PS 80
 Wallace CJ 201
 Wallston KA 322
- Walsh EG 236
 Walter JS 106, 107, 114
 Wang S 363
 Wannamaker E 213
 Waters K 279
 Watson G 397
 Weaver A 337
 Wegener S 315
 Weinrich M 429
 Weir D 277
 Weisenberger JM 418
 Weisgerber RA 445
 Weldon EJ 394
 Wells D 447
 Wells MS 209
 Wertsch JJ 12
 Wertz RT 446
 Whang JM 1, 2
 Wheeler JS 106, 107, 114
 White TP 302
 Whiteneck GG 98
 Whittaker S 397
 Whitten RP 347
 Whyte J 342
 Willard MJ 156
 Willems E 137
 Williams BT 360
 Williams DD 472
 Williams J 35
 Williams MA 250
 Williams SE 433, 436
 Wilson BA 83
 Wilson GL 161
 Winfield DL 347
 Winter M 471
- Winter WG 45
 Wirta RW 8
 Wise S 56
 Wolf PA 341
 Woo SLY 64, 306, 307
 Wood DW 440
 Wood R 71
 Woods D 470
 Woods WT 113
 Workman DS 183
 Wroblewski B 342
 Wu Y 20
 Wyngaarden J 476
 Wurster RD 106, 107, 117, 139
 Wylde MA 166
 Wyss CR 288, 290
- Xiao SJ 309
- Yager D 377
 Yaksh TL 96
 Yankee M 61
 Yelin EH 323
 Yiallovros G 189
 Young M 147
 Young RS 372
 Yund W 410
- Zajac FE 234
 Zelen M 361
 Zellner JR 166
 Zettl JH 6, 7
 Zomlefer M 278
 Zurif EB 434

HV1786
R266 Rehabilitation R&D
1987 Progress Reports 1987.

Copy 1

DATE DUE

HV1786
R266 Rehabilitation R&D
1987 Progress Reports 1987.

Copy #1

DATE

ISSUED TO

Reference

NOT TO CIRCULATE

AMERICAN FOUNDATION FOR THE BLIND
15 WEST 16th STREET
NEW YORK, N.Y. 10011

VA REHABILITATION DATABASE: THE DREAM

SCIENTIFIC

Journal of Rehabilitation Research and Development On-Line

PURPOSE

To provide greater accessibility to the Journal's scientific contents for use by rehabilitation researchers and other interested readers.

OBJECTIVES

Short-term:

- 1) "Publication" of the abstracts of individual articles immediately upon acceptance, well in advance of printed *Journal* publication.
- 2) Ready reference any time of day or week.
- 3) Expanded circulation of scientific research information.
- 4) Make *Journal* contents available to blind readers through use of speech synthesizers.

Mid-term:

- 1) Title/Author/Subject Index of all JRRD articles published, to be updated quarterly.

- 2) Allow readers to select material pertinent to their individual need.

- 3) Provide interactive forums for exchange on scientific issues.

Long-term:

- 1) Full text searching of rehabilitation literature.
- 2) One-stop access to rehabilitation literature.

Current contents:

- 1) **JRRD On-Line.** Abstracts of all articles published or accepted for publication to date.
- 2) *Rehabilitation R&D Progress Reports.*
- 3) Calendar of Events.
- 4) Current Publications of Interest.
- 5) Members, Technology Transfer Committee (A special interest group, part of RESNA—Association for the Advancement of Rehabilitation Technology).

CONSUMER

CLINICAL

Purpose:

To provide clinical personnel (e.g., physicians, physical therapists, audiologists, etc.) with current, accurate, and comprehensive information on rehabilitative devices.

First on-line:

Assistive listening and augmentative communication devices.

Planned enhancements:

All rehabilitative devices available or under development in the United States.

Purpose:

To promote the transfer of technology to potential users who can benefit from information on research results in many ways, including direct purchase of appropriate equipment, enrichment of ability to work with rehabilitation professionals, personal adjustment, and participation in service organization activities.

Current contents:

Selected, periodic reports on VA sponsored rehabilitation R&D research.

Desired contents (in addition to the above):

Selected biweekly news bulletins focusing on scientific developments of interest to consumers.

